SEPTEMBER, 1938
No. 333
Vol. XLII

MONTHLY
PRICE
3/6

The Journal of The Royal Aeronautical Society

With which is incorporated The Institution of Aeronautical Engineers

Edited for the Council by Capt. J. LAURENCE PRITCHARD, Hon. Fellow

CONTENTS FOR SEPTEMBER, 1938

Riveting Methods and Rivet Equipments used in the German Light Metal Aeroplane Construction ... ... *Pleines*

The Manipulation of the Boundary Layer ... *Richardson*

Abstracts from the Scientific and Technical Press

List of Selected Translations

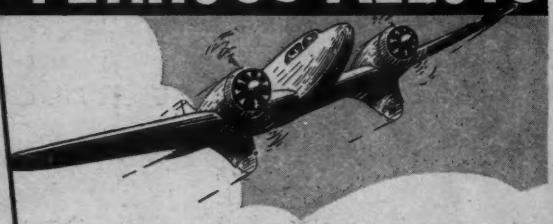
Reviews

THE ROYAL AERONAUTICAL SOCIETY WAS FOUNDED IN 1866

For Consistent Quality

ALUMINIUM AND COPPER ALLOYS · TPJ BRAND

NON-FERROUS ALLOYS



Produced in

NOTCHED BARS
INGOTS
ROLLING SLABS
WIRE BARS
STICKS & SHOT

Particular attention is drawn to our range of

STANDARDISED NON-FERROUS ALLOYS

for Aircraft and Admiralty work, which are produced under the direct control of our own Chemical and Physical Laboratories.

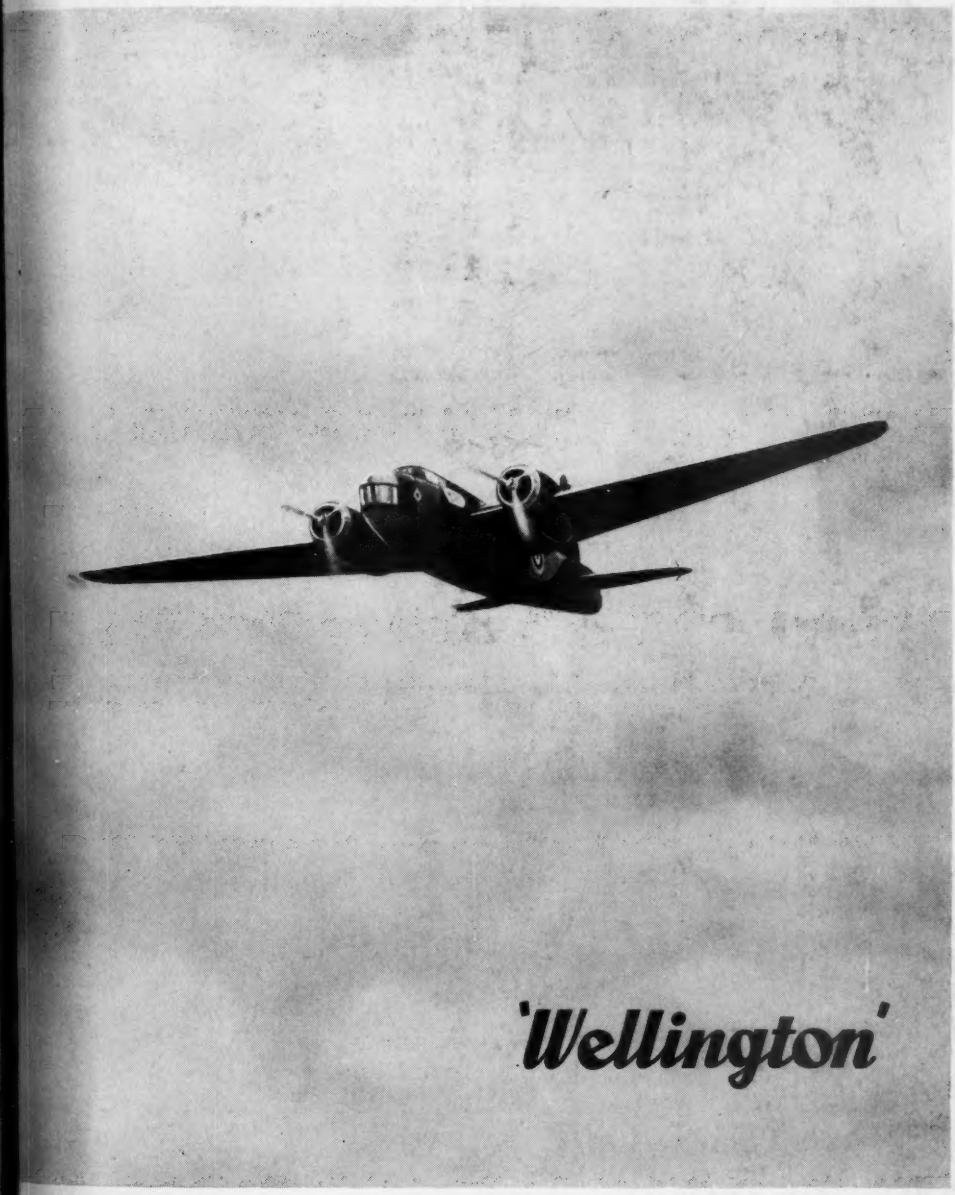
T. J. PRIESTMAN LTD
CUPRO FOUNDRY
LEOPOLD STREET, BIRMINGHAM
PHONE VIC 2581-2-3 GRAMS-SPECIFIC BIRMINGHAM

ON ADMIRALTY & AIR MINISTRY OFFICIAL LISTS

STRIP STEEL

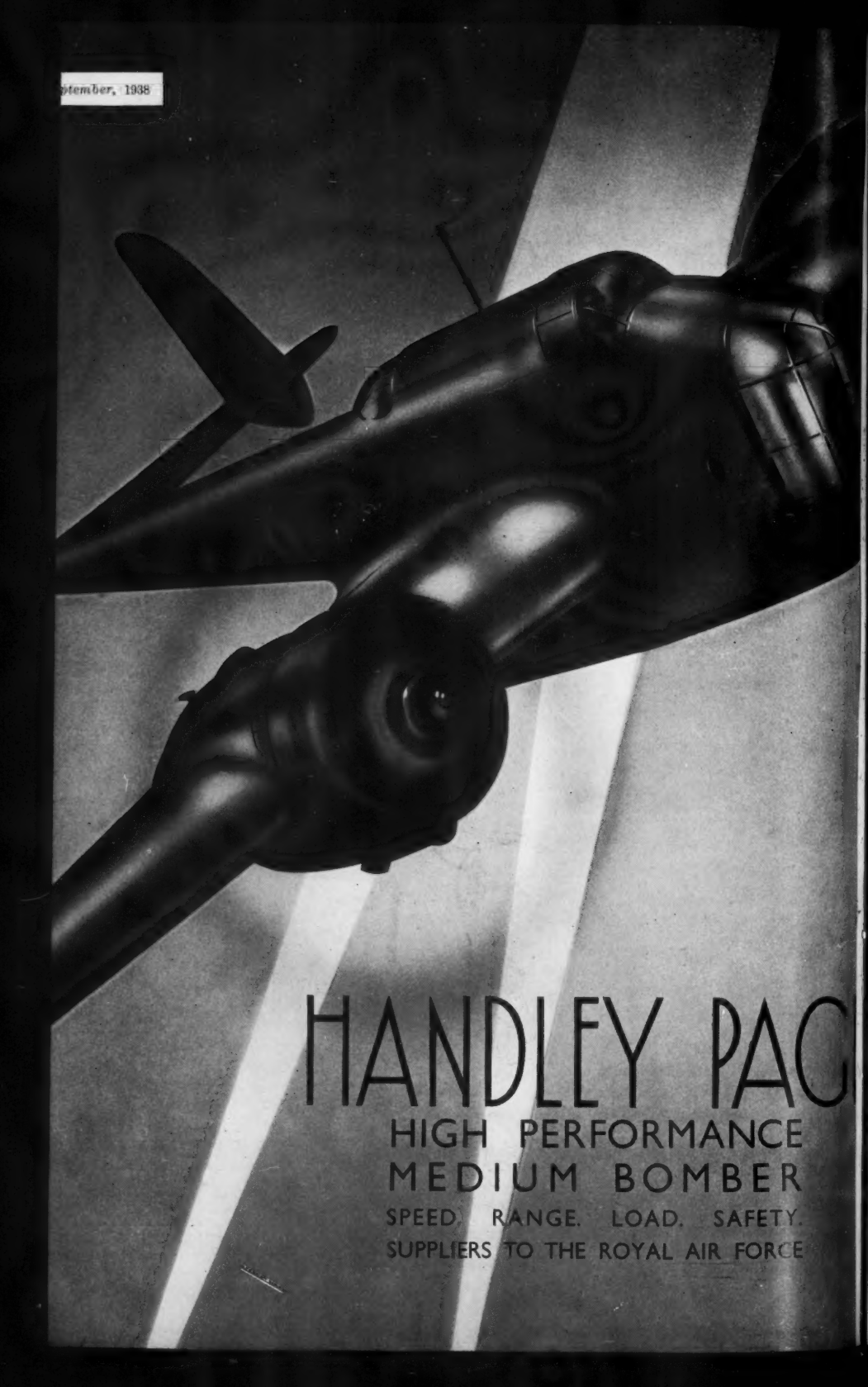
SPECIALISTS IN THE ROLLING AND
—— HEAT TREATMENT OF ——
AIRCRAFT STRIP AND SHEET STEEL.

J. J. HABERSHON & SONS, Ltd.,
HOLMES MILLS, ROTHERHAM.



VICKERS (AVIATION) LIMITED
WEYBRIDGE

EMPIRE EXHIBITION, SCOTLAND, Stand No. E9-13,18-22, PALACE OF ENGINEERING


HANDLEY PAG
HIGH PERFORMANCE
MEDIUM BOMBER
SPEED. RANGE. LOAD. SAFETY.
SUPPLIERS TO THE ROYAL AIR FORCE

ROLLS-ROYCE

Aero Engines

for

SPEED

and

RELIABILITY

Blackburn
AIRCRAFT

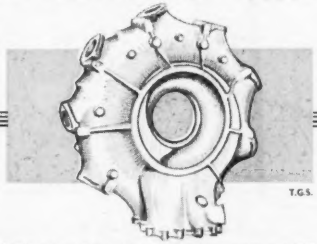
Protective Spiderweb of

STRENGTH

Size and weight were symbolical, once, of strength. But today, these things have given place to pedigree, training and intrinsic design for purpose. The "big man of business" is not necessarily a physical giant; the featherweight but scientific boxer fears not the fair-ground bruiser. Brain decides, not brawn. It is true at sea, on the road, in the air, and on rail—for here the judgment is by standards of performance, by speed, consumption, reliability; not by heaviness of weight. Weight is a quantity best reduced. And it can be cut with perfect safety and full protection—even in highly stressed parts—by using Hiduminium. No metal that is lighter, is as strong; none that is stronger, is as light. Hiduminium is the well-trained thoroughbred metal of the age; the metal in which brawn has been replaced by brain.

HIDUMINIUM R.R. ALLOYS

HIGH DUTY ALLOYS LIMITED · SLOUGH · BUCKS



TYPICAL BLOWER CASING CASTING IN HIDUMINIUM R.R. 50 ALLOY

" . . . certainly sets a high standard both in matter and make-up."—" The Times."

THE

ROYAL AIR FORCE QUARTERLY

(Published Quarterly—January, April, July and October.)

FULLY ILLUSTRATED

Recognised as the Official Organ of the Royal Air Force and Dominion Air Forces, the Editor being assisted by an Advisory Committee of Air Force Officers. By virtue of this fact it carries both distinction and great weight.

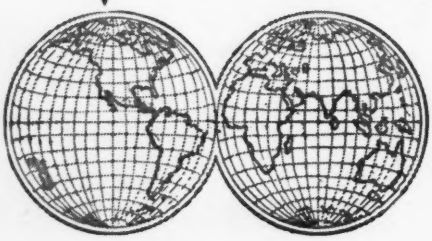
Articles on a wide range of subjects of great interest and value to all connected with Service or Civil Aviation.

Its circulation is world-wide and is not confined to the Services, for it is as popular with all sections of aviation as with the general Public.

The Journal is, in the words of a critic, " a delightful mixture of Service information, entertainment and instruction."

Hence its wide appeal !

Annual Subscription 20s. (post free) ; Single Copy 5s. (per post 5s. 6d.)

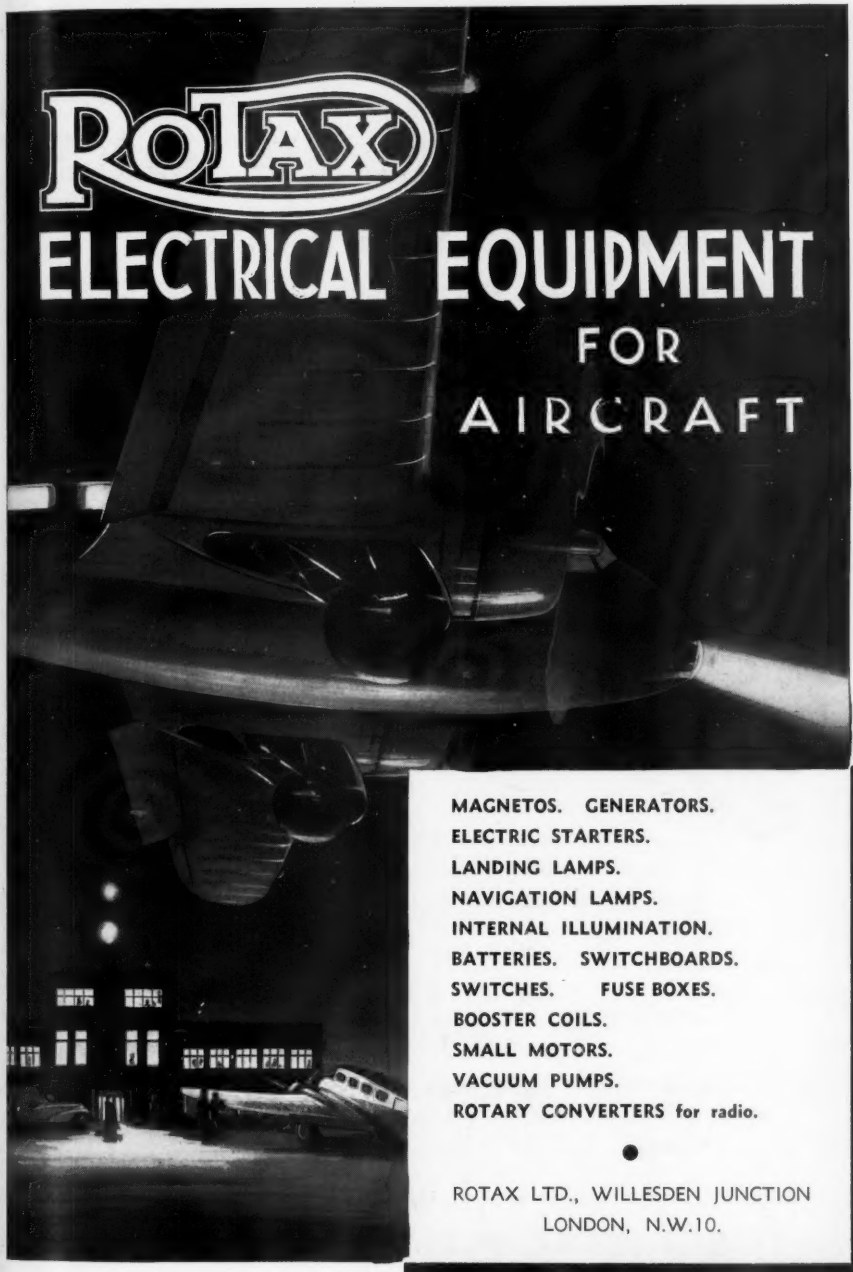


Of all Booksellers or direct from the Publishers :

GALE & POLDEN, Ltd.

Wellington Works - Aldershot

also at London and Portsmouth.



MAGNETOS. GENERATORS.
ELECTRIC STARTERS.
LANDING LAMPS.
NAVIGATION LAMPS.
INTERNAL ILLUMINATION.
BATTERIES. SWITCHBOARDS.
SWITCHES. FUSE BOXES.
BOOSTER COILS.
SMALL MOTORS.
VACUUM PUMPS.
ROTARY CONVERTERS for radio.

●

ROTAX LTD., WILLESDEN JUNCTION
LONDON, N.W.10.

Third Edition

HANDBOOK OF AERONAUTICS

Published under the authority of

THE COUNCIL OF THE ROYAL AERONAUTICAL SOCIETY

This is a comprehensive standard guide to modern practice in every department of aeronautical work. It is compiled by leading experts, with the assistance and co-operation of the Air Ministry, the Royal Aeronautical Society, the British Standards Institution, and many firms and individuals in the industry.

In the present edition the whole of the second volume is devoted to engines, and a new third volume deals with design data and formulae, airscrews, and general tables and conversion factors.

The three volumes together comprise nearly 1,400 pages of up-to-date information, profusely illustrated with photographs and drawings of the latest engines, components, instruments and other equipment, and including innumerable graphs, tables, lists of specifications and other data.

VOL. I. 639 pages **30/-** net (by post 30/6)
VOL. II. 483 pages **25/-** net (by post 25/6)
VOL. III. 250 pages **20/-** net (by post 20/6)

"Contains an enormous amount of valuable data"—
Aircraft Engineering.

"A book which can be recommended without any reservation to all engaged in the design and construction of aircraft . . . . solid and enduring."—*Journal of the Royal Aeronautical Society.*

Order from a bookseller or direct from

SIR ISAAC PITMAN & SONS, LTD.
Parker Street, Kingsway, London, W.C.2

THE NEW IMPERIAL AIRWAYS

"ENSIGN"

AIR LINER

Designed and Constructed by

SIR W. G. ARMSTRONG WHITWORTH AIRCRAFT LTD.

WHITLEY, COVENTRY.

3458

Cellactite

for AERODROME BUILDINGS

CELLACTITE steel-cored corrugated sheets have proved ideal for hangars and aerodrome buildings of all sorts. They provide permanent protection, whether installed as roofing or vertical cover, and the lightness and non-breakability of CELLACTITE make it ideal for the large sliding doors usual on such buildings.

Contracts include extensions for Fairey Aviation Co., Ltd., the Bristol Aeroplane Co., Ltd., and for Handley-Page, Ltd., numerous air sheds and buildings for the Air Ministry, and the Dekheila, Mersa Matruh, Almaza and El Arish hangars for the Civil Aviation Authorities in Egypt.

May we send you the CELLACTITE Reference Catalogues giving full particulars both of the sheeting and of the highly efficient CELLACTITE "Medway" Roof Ventilator in uniform material ?

HEAT INSULATOR

•

RESILIENT

•

LIGHT

•

STEEL-CORED

•

PERMANENT

•

EXCEPTIONAL STRENGTH

Large Aeroplane Shed for Fairey Aviation Co., Ltd., roofed and side sheeted with CELLACTITE.

CELLACTITE & BRITISH URALITE, LTD.,

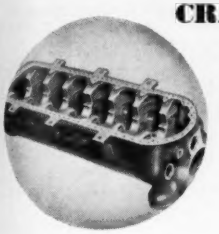
Lincoln House - 296-302 High Holborn - London, W.C.1

Phone: Holborn 5291-2, 8824 Grams: Cellactite, Holb., London Works: Higham, Kent

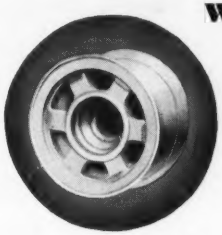
WORKS AT "Keep Britain busy" HIGHAM-KENT

TAS/Cel 186

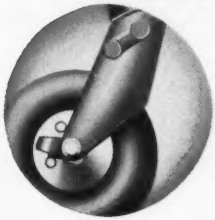
CRANKCASES



WHEELS



TAIL FORKS



Extreme Lightness with great strength

BECAUSE they are 40% lighter than aluminium — and yet possess ample strength — "Elektron" magnesium alloys enable designers to produce speedier aircraft with increased range and greater carrying capacity for the same horse power. Applications are countless and include:—

CRANKCASES

Many of the world's most famous engines employ crankcases in "Elektron" magnesium alloys. Two typical examples are the D.H. "Gipsy 12" and the Napier "Rapier."

WHEELS

140 lb. is saved in a large Dunlop wheel, by the use of "Elektron" Magnesium Alloys.

TAIL FORKS

Few parts receive greater stress than tail-wheel carrying forks — an application in which "Elektron" has achieved great success because it combines lightness with strength.

FAIRINGS

"Elektron" is widely used for fairings owing to its exceptional lightness. A new sheet alloy capable of extensive cold-working is now being produced.

The use of "Elektron" would give improved performance to the aircraft and engines you design or produce. Why not write for details?

FAIRINGS

AND MANY OTHER PARTS

ELEKTRON

REGISTERED TRADE MARK

MAGNESIUM ALLOYS

MADE IN GREAT BRITAIN—AMPLE SUPPLIES AVAILABLE

Sole Producers and Proprietors of the Trade Mark "Elektron"
MAGNESIUM ELEKTRON LIMITED
Works, near Manchester

Licensed Manufacturers
Castings
STERLING METALS LIMITED
Northey Road, Foleshill, Coventry

THE BIRMINGHAM ALUMINIUM CASTING (1903) COMPANY LIMITED
Birmid Works, Smethwick, Birmingham

J. STONE & COMPANY LIMITED
Deptford, London, S.E.14

Sheet, Extrusions, Forgings & Tubes
JAMES BOOTH & CO. (1915) LIMITED
Argyle Street Works, Nechells, Birmingham, 7

Sheet, Extrusions, Etc.
BIRMETALS LIMITED
Woodgate, Quinton, Birmingham

Suppliers of Magnesium and "Elektron" Metal for the British Empire
F. A. HUGHES & CO. LIMITED
Abbey House, Baker St., London, N.W.1

"ELEKTRON"—THE LIGHTEST CONSTRUCTIONAL METAL

T.G.S.

AVIATION'S PREMIER PISTON RING

HIGH TENSILE STRENGTH
HIGH ELASTIC VALUE
MAINTAINS RING PRESSURE UNDER EXTREME HEAT
DOES NOT SCUFF

Manufactured by
THE BRITISH PISTON RING COMPANY, LTD.
COVENTRY

Specialists in the manufacture of
CAST IRON ALLOYS FOR SPECIAL HIGH-DUTY REQUIREMENTS

H.P.

THE JOURNAL OF THE
AERONAUTICAL SCIENCES

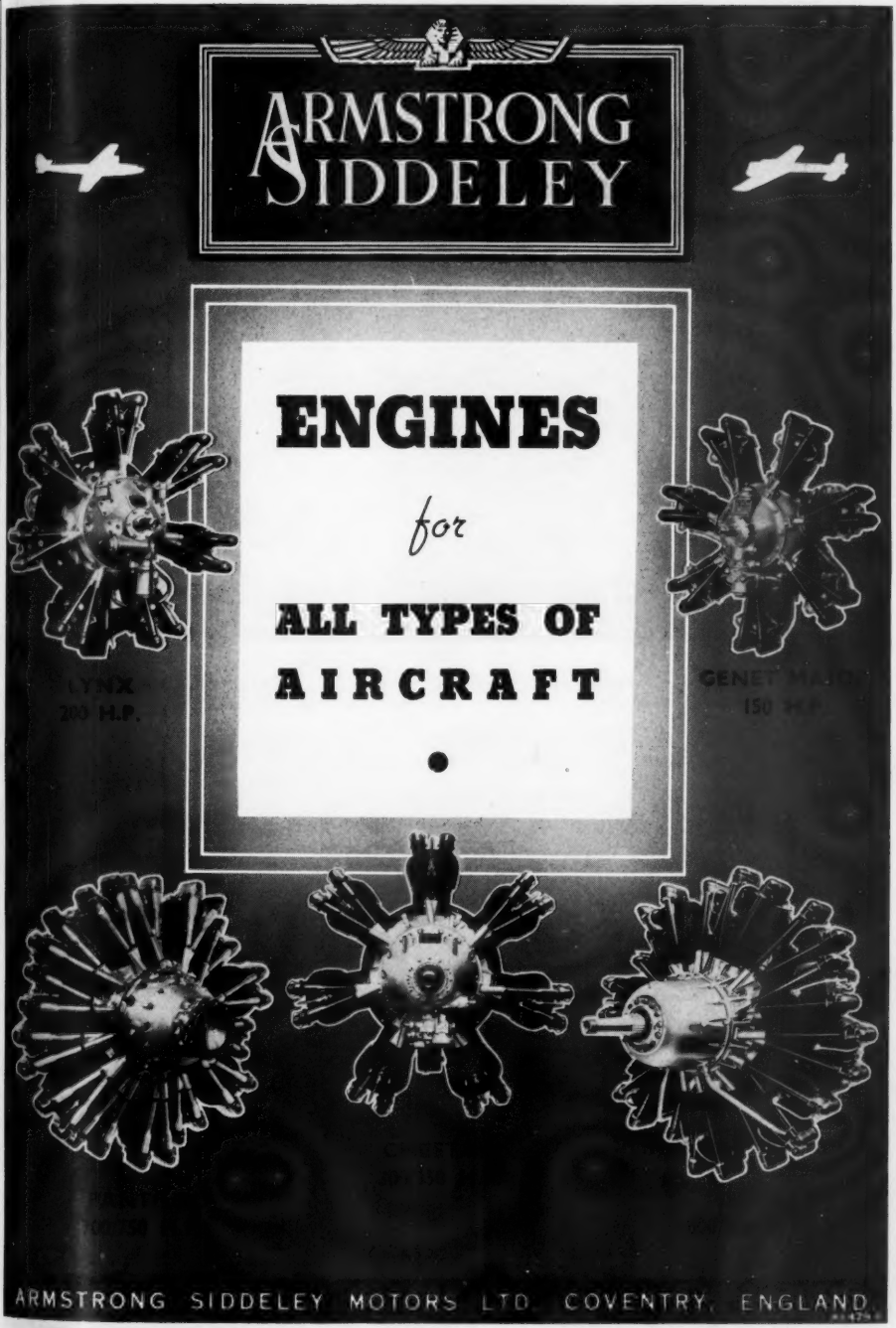
edited for and by specialists in the aeronautical sciences

$6 per year

Published monthly

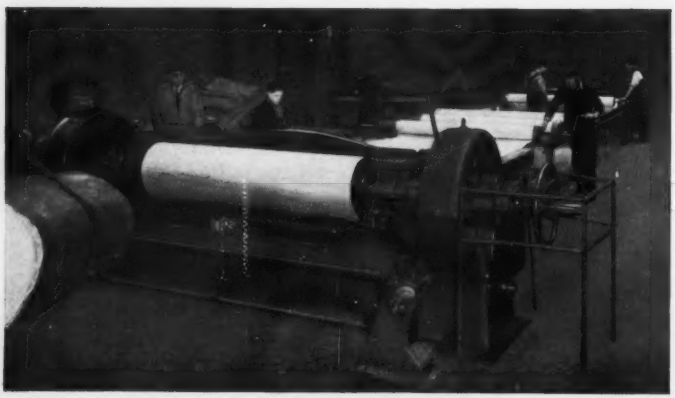
by

THE INSTITUTE OF THE AERONAUTICAL SCIENCES
5431 R.C.A. BUILDING, 30 ROCKEFELLER PLAZA
NEW YORK, N.Y.


ARMSTRONG SIDDELEY
ENGINES
for
ALL TYPES OF AIRCRAFT
LYNX 200 H.P.
GENET MAJOR 150 H.P.
ARMSTRONG SIDDELEY MOTORS LTD. COVENTRY, ENGLAND.

"Flight" photo.

WELLWORTHY PISTON RINGS LTD., LYMINGTON, HANTS



Photograph shows the special peeling machinery for this high-grade wood

DURAPLY HIGH DUTY PLYWOOD

REG'D

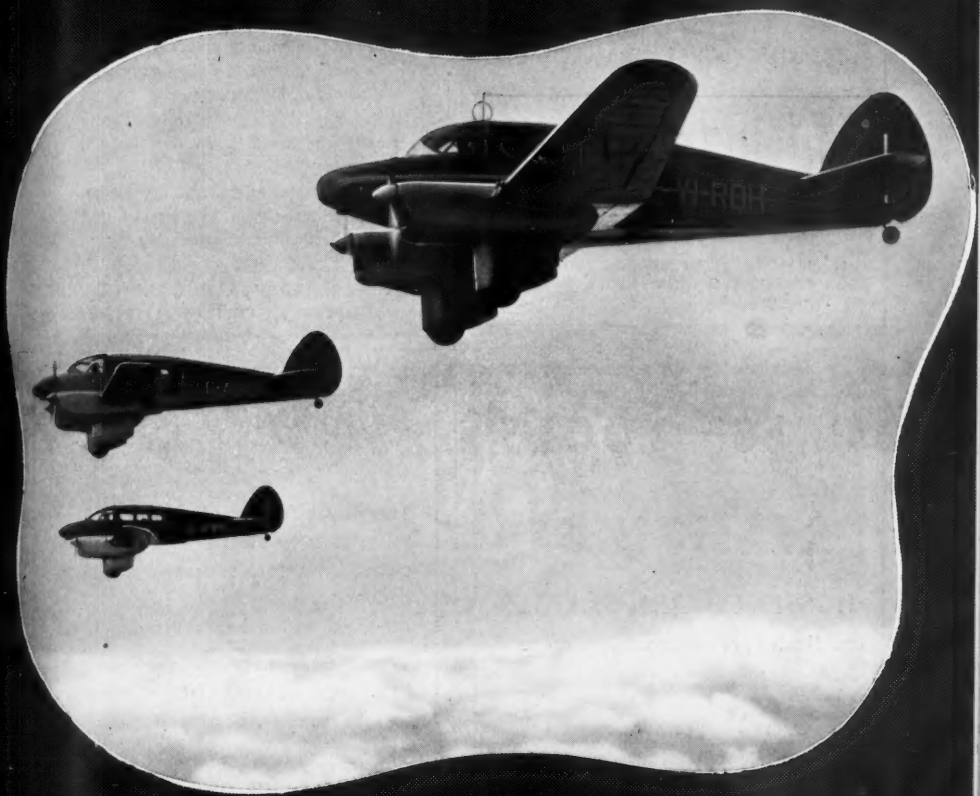
Water proof - heat proof - boiling proof - Bonded with Bakelite

these are the characteristics of Duraply. If you have any demand for a very high grade plywood for a special purpose, send us your enquiries. For minimum lots of 200 pieces, each size, we can supply in CUT SIZES.

F. HILLS & SONS, LTD., TRAFFORD PARK, MANCHESTER 17
Telephone : Trafford Park 2661 (6 lines)
And at Norton Road, Stockton-on-Tees. Telephone : 6195 (2 lines)

Standardising

SMITH'S INSTRUMENTS



PERCIVAL 'Q6' AIRCRAFT (D.H GIPSY VI ENGINE)

HUSUN COMPASS

● **HOBSON** INDUCTION PRESSURE (BOOST) CONTROLS

● **HOBSON-PENN** AUTOMATIC MIXTURE CONTROLS

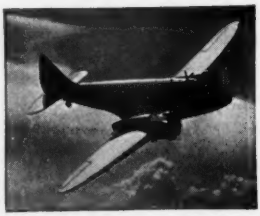
● **HOBSON** ELECTRICAL ICE DETECTOR (ENGINE)

● **HOBSON** PILOT'S COCKPIT CONTROLS

FOR ALL TYPES OF AERO ENGINES

CLAUDEL-HOBSON
Carburetters

H. M. HOBSON (AIRCRAFT & MOTOR) COMPONENTS LTD.
47-55, The Vale, Acton, London, W.3



The
AIRSPEED AERONAUTICAL COLLEGE

provides complete practical training in modern aircraft design, construction and maintenance.

Evening lectures run concurrently and are based upon the R.Ae.S. examinations.

The syllabus offers training for an assured career in commercial and civil Aeronautical Engineering.

Write for Particulars to: THE PRINCIPAL
AIRSPEED AERONAUTICAL COLLEGE
THE AIRPORT, PORTSMOUTH, England

PRESS TOOLS
and
STAMPINGS

JIGS, FIXTURES, GAUGES
to limits of extreme accuracy

Over 30 years successful experience with difficult problems.

PROMPT DELIVERIES

E. BROWN
17½ High St., Wimbledon, S.W.19

AVIATION LECTURES

The Royal Aeronautical Society has a series of standard lectures, illustrated by lantern slides, suitable for delivery before Public Schools and other educational establishments.

These lectures are available to members and others. Full particulars will be sent free on application.

The Society has available some 5,000 slides on every branch of aviation.

Slide List—price **1s. 3d.** post free.

THE ROYAL AERONAUTICAL SOCIETY
with which is incorporated "The Institution of Aeronautical Engineers"
7, ALBEMARLE ST., LONDON, W.1
Telephone: Regent 6800

LIGHT
ALLOY PERFECTION
through BIRMETALS'
LABORATORIES
BIRMETALS
1
2
3
4
5
6
1. A CORNER OF THE PHYSICAL LABORATORY showing an Amsler Repeated Impact Machine and one of the fatigue test machines.
2. THE FIRST PHOTOELECTRIC MICROPHOTOMETER of its type in this country for analysis of light alloys.
3. VIEW IN THE METALLURGICAL DEPARTMENT showing the completely equipped dark rooms and a Vickers projection microscope.
4. VICKERS HARDNESS MACHINE which is in constant use on routine control and metallurgical research work.
5. TENSILE TEST MACHINES on which samples of every batch of alloys produced are tested for proof stress, strength, elongation, etc.
6. THE CHEMICAL LABORATORY, abundantly equipped for routine control analysis.
BIRMETALS LIMITED. WOODGATE. QUINTON. BIRMINGHAM
A COMPONENT COMPANY OF BIRMID INDUSTRIES LTD.
T.G.S.

A MILLION FLYING HOURS...

Since the British Aviation Insurance Company issued its first policy as pioneer-specialists in aviation insurance over twelve years ago, it has effectively covered the flying risks of more than a million hours. During this period, coverage for ground and mooring risks of every kind has also been maintained.

Where else could be found such a fine record of practical achievement? To-day this unique wealth of experience enables the Company to offer aircraft manufacturers and owners the soundest and most advantageous insurance facilities in the world . . . all over the world. Every phase of aviation insurance is covered by the Company, which numbers among its clients the majority of leading British Air Lines and Aircraft Manufacturers.

Individual insurance problems receive the immediate personal attention of the Company's experts, whose advice and assistance will gladly be given at any hour of the day or night.

THE BRITISH AVIATION INSURANCE COMPANY LTD.

3-4 LIME ST., LONDON, E C.3

Telephones: During Office Hours 9.30 a.m — 5 p.m. Mansion House 0444 (5 lines) At all other times: Speedwell 5510 Rickmansworth 591 Gerrards Cross 3024

Telegrams: Aviacoy, Lime, London

PARIS Office :
1, Rue des Italiens, Paris.
Telephone: Provence 7777
Telegrams: Aviacoy, PARIS

Underwriter and Principal Surveyor:
Captain A. G. Lamplugh, F.R.Ae.S, M.I.Ae.E., F.R.G.S.

REMOTE CONTROL

The G.A.L. Smoke Trail can be literally started at the touch of a switch, away in the control tower. It can be cut off in the same way.

A dense, white plume of smoke is produced, unmistakable and reliable.

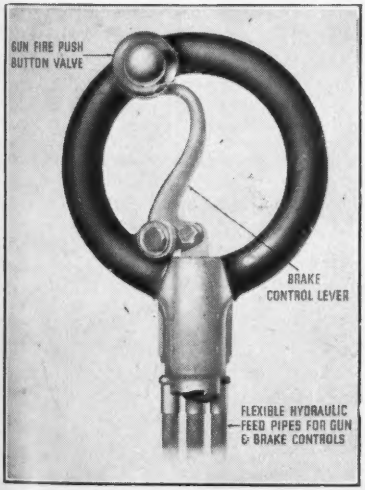
The Smoke Trail works day and night without attention, and at night, moreover, it can be illuminated if you wish. It carries fuel for a week without replenishment; upkeep costs nil. Placed in a concrete pit and flush with the ground, the mechanism offers no obstruction to landing aircraft, which can safely touch down even on the pit cover itself. We shall be glad to demonstrate the G.A.L. Smoke Trail at any time. Write, or 'phone, Feltham 2604.

The G.A.L SMOKE TRAIL

General Aircraft Ltd., London Air Park
Feltham, Middlesex

Keymer

PALMER



complete

Brake & Gun-fire Control

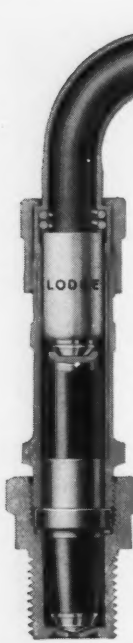
(power-hydraulic)

★

Full details of this latest Palmer achievement are now available

★

THE PALMER TYRE LTD.
THAMES HOUSE, MILLBANK
LONDON, S.W.1



LODGE

RADIO-SCREENED PLUGS
and improved
SCREENED CABLE FITTINGS

Completely opaque to electrical radiation

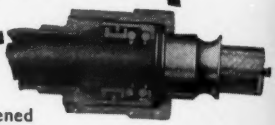


Illustration at left shows the Lodge radio-screened aviation plug complete with coupling for screening harness (conduit type), using ordinary insulated cable. Inset at right: Alternative coupling for metal braided cable.

There are approved types of Lodge radio-screened and unscreened aviation plugs suitable for all makes and types of aero engines. Unscreened types also are available with alternative terminal fittings.

On British Air Ministry Approved List

Further particulars of Lodge aviation plugs will be forwarded upon request to LODGE PLUGS LTD., RUGBY

WORLD'S LAND SPEED RECORD

Capt. G. E. T. Eyston used Lodge plugs in the Rolls-Royce aviation engines of 'Thunderbolt'

AVRO

AVRO

ASTLE FIBRE Aeroplane parts...

re a model of accuracy

THE SKY'S THE LIMIT so it seems for the uses of "Castle Fibre." Over 500 different parts — fair leads, washers, distance pieces, gaskets and other essential components in modern aircraft are now made from "Castle Fibre."

"Castle Fibre" is light yet tremendously strong — is impervious to atmospheric conditions, is easily machined, possesses good insulating properties and withstands excessive wear especially where vibration is expected. Our Technical Department will gladly suggest ways in which "Castle Fibre" can help you in increasing efficiency and decreasing overheads.

VULCANISED FIBRE LTD · GUILDFORD · SURREY

'one:—Shalford 199 & 200 'Grams:—'Vulcanised,' Guildford

B T-H

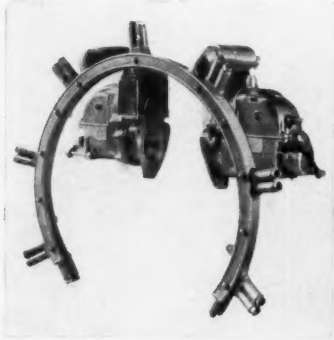
MAGNETOS & HARNESS

SCREENED IGNITION EQUIPMENT

Approved by the Air Ministry

Illustrated —
Equipment as fitted to
Bristol "Perseus" and
"Aquilla" engines.

Can be supplied for all types of Aero Engines



BTH COVENTRY

THE BRITISH THOMSON-HOUSTON COMPANY LIMITED, COVENTRY, ENGLAND

A2471N

The

Royal Aeronautical Society

with which is incorporated

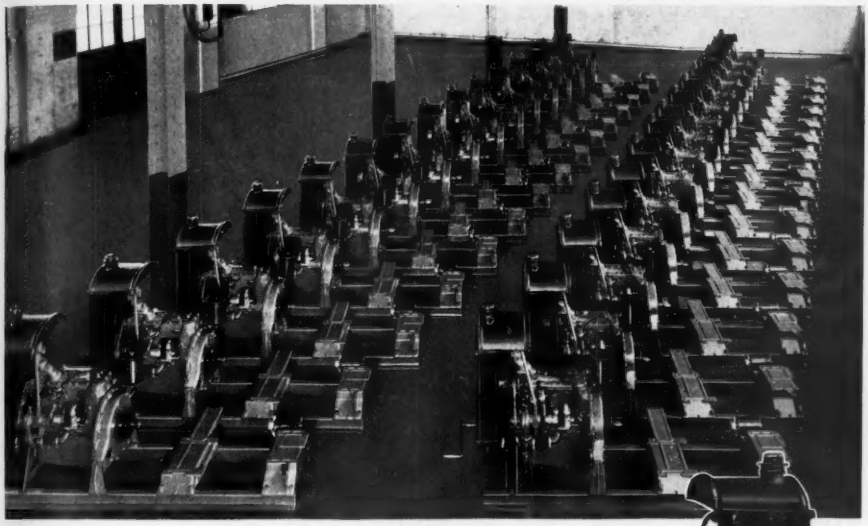
The Institution of Aeronautical Engineers

INFORMATION BUREAU

ONE of the objects of the Society is the provision of technical information on all branches of aeronautics and its allied sciences. For that purpose a card index of information was begun in January, 1927, and now contains many thousand entries. The information given on these cards is at the disposal of all members of the Society free of charge.

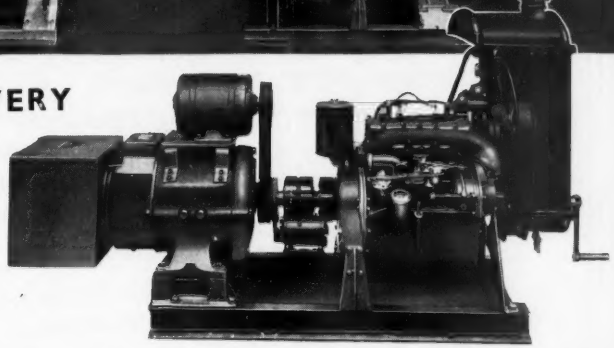
COVENTRY CLIMAX ENGLAND

POWER UNITS *for* GENERATORS



QUICK DELIVERY

These units are now in production at our Coventry works and the above photograph shows part of an order ready for despatch. We can arrange for IMMEDIATE DELIVERY in cases where this is urgently required



COVENTRY CLIMAX POWER UNITS are being supplied in quantities to Government requirements. The unit is entirely self-contained, quick starting, reliable and economical, and readily transportable. Here is the perfect source of power supply for emergency and stand-by purposes, or for building into mobile units such as flood-lights, welding plant, etc.

In the unit illustrated above the engine is adapted to drive a Generator and forms an ideal installation for aerodromes or similar buildings that may be remote from town's supply or for auxiliary supply in case of emergency. Particulars from COVENTRY CLIMAX ENGINES LTD., COVENTRY

AN IDEAL SELF-CONTAINED SOURCE OF POWER FOR EMERGENCY OR AUXILIARY USE

H.P.

THE ASSEMBLY OF AN AERO ENGINE

Recent research, notably by electron diffraction analysis, shows clearly the importance of protecting a working face from abrasion during running-in. Adequate protection in lubrication encourages the formation of a wear-resisting skin on the metal while the smoothing process is accomplished more by plastic deformation than by abrasion. The practice of assembling and running-in with oil containing 'dag' colloidal graphite is now widespread among engine manufacturers, being used or approved by over thirty, including Austin, A.E.C., Daimler, Lagonda, Singer and Standard. Not only does the slippery surface formed on the rubbing faces provide the necessary protection, but initial friction in the engine is reduced.

Further information on the above may be obtained on application to the Technical Dept. of

E. G. ACHESON LTD.

THAMES HOUSE, MILLBANK, LONDON S.W.1

Tel.: Vic. 5644 (4 lines) Works : Plymouth

dag
REG. TRADE MARK
COLLOIDAL PRODUCTS

Do you know? what these are.

INTERNAL TYPE

EXTERNAL TYPE

They are SEEGER PATENT CIRCLIPS—a precision fixture without which designers cannot get the best results.

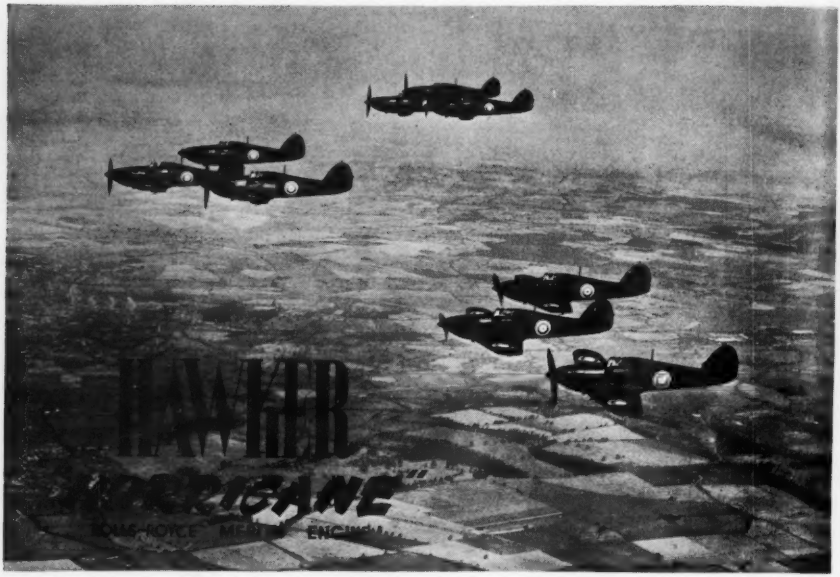
By virtue of having their width tapered in accordance with scientific principles they are the only circlips which always remain truly circular on the contact periphery. They therefore exert the maximum possible uniform pressure in the grooves to which they are fitted. The internal type locates ball races, etc., in sleeves ; the external type locates them on shafts.

Write for fully descriptive literature.

SEEGER PATENT CIRCLIPS

The Automotive Engineering Co. Ltd., The Green, Twickenham, Middsx.

Manufacturers and Distributors for the British Empire

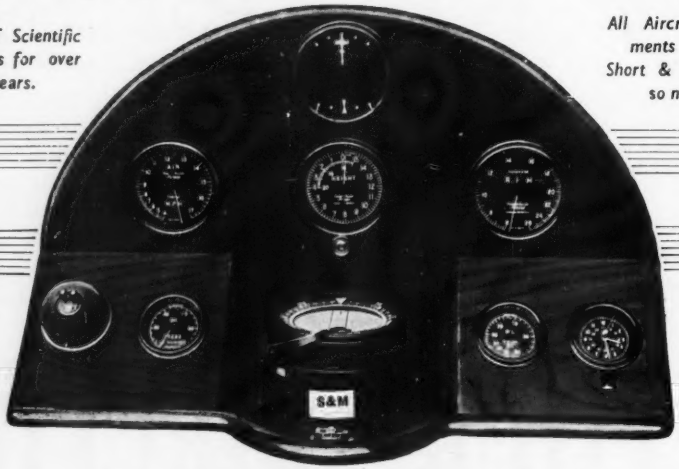


HAWKER AIRCRAFT LTD.
DESIGNERS AND CONSTRUCTORS OF ALL TYPES OF MILITARY AIRCRAFT
Works: KINGSTON-ON-THAMES Aerodrome: BROOKLANDS

INSTRUMENTS FOR AIRCRAFT

Makers of Scientific Instruments for over 70 years.

All Aircraft Instruments made by Short & Mason are so marked.



Full particulars on application.

Telephone: LARkswood 3371

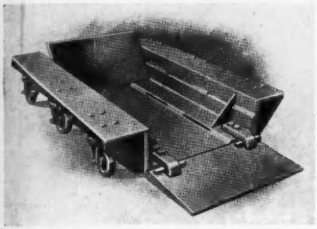
SHORT & MASON LTD.
THE INSTRUMENT HOUSE
WALTHAMSTOW ⑰ LONDON, E.17

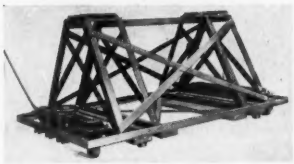
Cables. "Aneroid, London"

Telegrams: "Aneroic Phone, London"

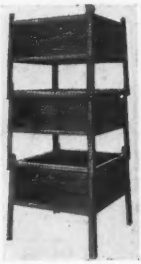
LIFTING - CONVEYING - STORAGE

EQUIPMENT SPECIALLY DESIGNED
FOR AIRCRAFT MANUFACTURE





Above : TURNING FIXTURES
Left : TRUCK
Right : STACKABLE STILLAGES



GEO. W. KING LTD.

HARTFORD WORKS, HITCHIN, HERTS

'Phone : Hitchin 424/5/6 'Grams : "Kings Hitchin"

Synoptic & Aeronautical Meteorology

By HORACE ROBERT BYERS

In Charge of Air-Mass Analysis Section, U.S. Weather Bureau

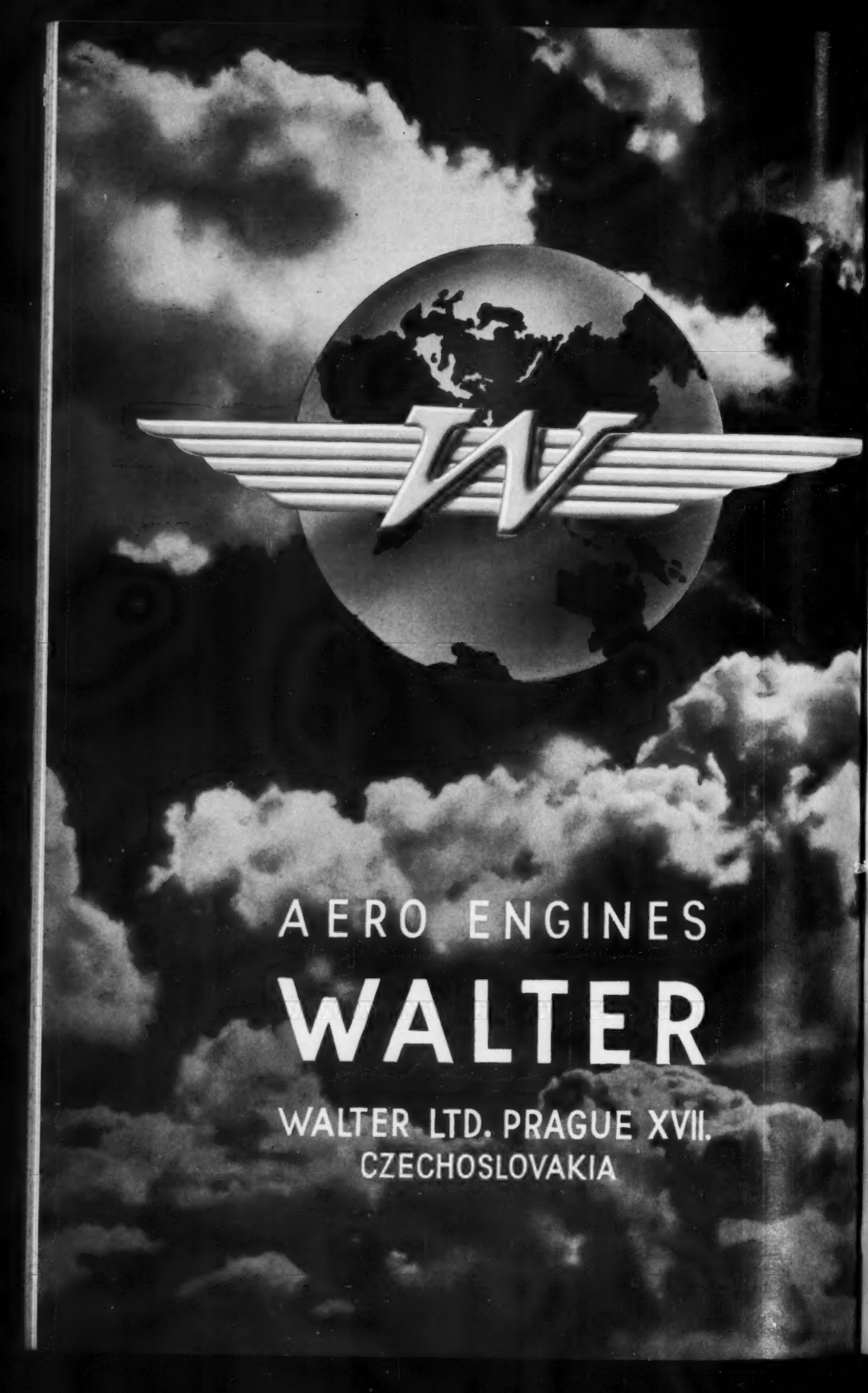
279 pages, 9 x 6, 58 illustrations, 21/- net

Chapter Headings

Preface
Introduction
Radiation and the Temperature Distribution of the Atmosphere
Stability, Instability and Vertical Motions
Air Masses—Their Characteristics and Modifications
The General Circulation
The Secondary Circulations — Cyclones and Anti-cyclones
Changes in Air Masses with Lifting
The Air Masses of North America
Air-Mass Analysis on the Synoptic Chart
Weather Forecasting
Condensation and Precipitation
Fog
The Thunderstorm, the Tornado and Waterspout
The Formation of Ice on Aircraft
Atmosphere Turbulence and the Wind Structure Near the Surface of the Earth
Dust Storms
Index

McGraw-Hill Publishing Company Ltd.

Aldwych House London, W.C.2


AERO ENGINES
WALTER
WALTER LTD. PRAGUE XVII.
CZECHOSLOVAKIA

THE JOURNAL
OF
THE ROYAL AERONAUTICAL SOCIETY
With which is Incorporated The Institution of Aeronautical Engineers.

CONTENTS FOR SEPTEMBER, 1938

		PAGE
1	RIVETING METHODS AND RIVET EQUIPMENTS USED IN THE GERMAN LIGHT METAL AEROPLANE CONSTRUCTION, BY DR.-ING. WILHELM PLEINES	761
2	THE MANIPULATION OF THE BOUNDARY LAYER, BY E. G. RICHARDSON, B.A., Ph.D., D.Sc.	816
3	ABSTRACTS FROM THE SCIENTIFIC AND TECHNICAL PRESS	839
4	LIST OF SELECTED TRANSLATIONS	860
5	REVIEWS	862
6	CORRESPONDENCE	865

THE JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY *was founded in* 1897 *in succession to the* ANNUAL REPORTS.

For the opinions expressed in Papers that are signed or initialled the authors alone are responsible. None of the Papers or paragraphs must be taken as expressing the opinion of the Council of the Royal Aeronautical Society, unless such is definitely stated to be the case.

The Journal is published monthly at the Offices of the Society, 7, Albemarle Street, Piccadilly, London, W.1.

Subscription per annum, £2 - 4 - 6 post free; Single Numbers 3/6. or 3/9 post free.

All communications for publication in the Journal, or on general matters affecting the Society should be addressed to—

The Secretary and Editor,
J. Laurence Pritchard,
7, Albemarle Street, W.1.

The Society's Bankers are Messrs. Coutts & Co.

All communications respecting Advertisement matters should be addressed to—
The Advertisement Manager, Journal of the Royal Aeronautical Society,
7, Albemarle Street, W.1.

Telephone: Regent 6800 & 2736. Telegraphic Address: "Didaskalos, Piccy. London."
Or to—
T. G. Scott & Son, Ltd., 63, Ludgate Hill, London, E.C.4. Telephone: City 4211.

The **COLLEGE** of
AERONAUTICAL ENGINEERING
President: THE VISCOUNT WAKEFIELD

Engineering Works: CHELSEA, S.W.3 Aerodrome: BROOKLANDS, SURREY.
Residential Hall: WIMBLEDON PARK.

Provides students with an engineering training to meet the requirements of Civil and Commercial Aviation.

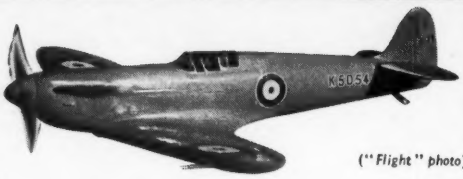
The Curriculum is based on the Official regulations for the granting of Air Ministry Certificates and, in addition, combines a maximum of practical experience with training in Administration.

The number of students admitted is limited and candidates will be accepted, in the first instance, for a Probationary Term only.

THE SYLLABUS MAY BE OBTAINED FROM

The COLLEGE of AERONAUTICAL ENGINEERING, CHELSEA, S.W.3

We are SUB-CONTRACTORS for components used in the Supermarine "Spitfire."



("Flight" photo)

Send us your enquiries

Specialists in the manufacture of all types of complete assemblies and details. Wings, ribs, ailerons, flaps, elevators, tail-units, etc.

Quick delivery

Full protective and other treatments.

Full inspection organisation approved by A.I.D.

J. SAMUEL WHITE & CO. LTD.

SOMERTON WORKS TELEGRAMS: WHITE, SOMERTON, COWES TELEPHONE: COWES 400 COWES, I. of W.

"Bristol"

BLENHEIM BOMBER

—a notable "Bristol" high-performance aircraft and an important factor in national defence—is the standard equipment of many squadrons of the R.A.F. both at home and overseas.

THE BRISTOL AEROPLANE CO. LTD., FILTON, BRISTOL.

The 631st Lecture to be delivered before the Royal Aeronautical Society since its foundation on January 12th, 1866.

PROCEEDINGS.

A meeting of the Society was held at the Institution of Mechanical Engineers, Storey's Gate, London, on Thursday, March 3rd, 1938, when a lecture was read by Dr.-Ing. W. Pleines on "Riveting Methods and Rivet Equipments Used in German Light Metal Aeroplane Construction."

In the chair: Mr. A. H. Hall, Vice-President of the Society.

The CHAIRMAN: It was his pleasure to introduce Dr. Pleines, who had come over from Germany to give a lecture on riveting methods and rivet equipments used in the German light metal aeroplane construction. Dr. Pleines had had a very wide experience in aeronautics. He was trained under Dr. Hoff and was chief technician under him in Berlin, where he made a special study of riveting methods. For ten years he was flying engineer to the D.V.L., but he had another claim to fame in that he was the first man to fly flight tests with the Handley-Page slot in Germany. Since he left the D.V.L. he had been a consulting engineer and a riveting expert, and was a director of a firm (Frankfurter Maschinenbau—AG, vorm. Pokorny und Wittekind, Frankfurt a/Main), which dealt with riveting and riveting equipment. Consequently he was a leading expert on that subject, as no doubt would be appreciated from the very interesting lecture he was about to give.

In conclusion, the Chairman remarked that although Dr. Pleines spoke English well, he had a somewhat natural diffidence in speaking in English before a British audience, and he had therefore asked Captain Pritchard, the Secretary of the Society, to read the paper for him.

Dr. PLEINES: Before the paper was read he wished to express his appreciation of the very kind invitation to give this lecture before so learned an assembly of British aviation experts. At the same time he expressed his regret that he did not think his English was sufficiently good to enable him to read the paper, and he was grateful to Captain Pritchard for having undertaken to do so.

RIVETING METHODS AND RIVET EQUIPMENTS USED IN THE GERMAN LIGHT METAL AEROPLANE CONSTRUCTION

By Dr.-Ing. WILHELM PLEINES.

(I) FUNDAMENTAL NOTIONS ON RIVETING IN LIGHT METAL AEROPLANE CONSTRUCTION.

For many years there have been used in aircraft construction aluminium alloys to a steadily increasing extent, and particularly alloys of Al.-Cu.-, Mg. and Al.-Cu. capable of being improved by heat treatment. Among the different methods known for permanent connection of structural parts, the rivet is still to-day the most reliable and safest connecting element. According to the special quality of this light metal group, due to their natural material characteristics and owing to the fact that in most cases the connections of aircraft structural parts are very complicated and highly stressed, the rivets are always driven cold. Due to these conditions, the tools, machines and working methods for strengthening

of riveting diverge essentially from the commonly known riveting methods of general machine construction. In the course of my lecture I shall give further details regarding these questions.

Cold riveting and its wide adaptability are facilitated by the following facts:

(1) In metal aeroplane construction rivets are commonly used in relatively small sizes; for structural parts of " stressed skin " construction, actually in use, the rivet diameters are generally between 2.5 to 3 mm. The quantity of rivet sizes between 4 and 8 or maximum 10 mm. diameter is relatively small. Rivets of 5 to 8 mm. were principally used for structures with comparatively thick walls. On account of the special " open " design of these parts, there are in most cases machine riveting methods applicable for them. Practical experience has taught us however that for all these rivets sizes cold forming is principally possible. Also materials of the magnesium alloys group, *e.g.*, " Electron " are riveted cold. For highly stressed parts of electron there are used Hy- or Mg-rivets, in order to avoid corrosion, while at spots undergoing little stress, rivets of pure aluminium are employed.

(2) As most of the rivet materials used at the present time consist of self-hardening alloys, their workability and forming characteristics can be increased by heat treatment just before driving. This heat treatment includes three stages of operation, viz. *annealing*, *quenching* and *ageing*.

Baustoff material	Niet – ϕ rivet diameter d_N	Nietteilung rivet spacing t
Eisen, Stahl	$= \sqrt{5 \cdot s} - 0.4$	$= 2.6 \cdot d_N + (0.5 \div 1.5)$
Iron, steel		
Leichtmetalle	(1) $= 3.0 \cdot s$	(1) $= > 10 \cdot d_N$
Light metal alloys	(2) $= (2/2.5) \cdot \sqrt{s}$	(2) $= > 8 \cdot d_N$

s = Blechstärke (mm.).
Sheet thickness.
(1) für $s \leqq 1.0$ mm.
for
(2) für $s \geqq 1.0$ mm.
for

d_N/s – Verhältnisse und Nietteilungen t im Eisen-, Stahl- und im Leichtmetallbau, gültig für 1 bis 3 schnittige Nietverbindungen.

d_N/s – ratios and rivet spacing t for iron, steel and light metal constructions, usual for simple to treble riveted joints.

Table I.

Annealing is mainly done in a salt-bath, less frequently in an air bath, with a constant temperature of about 505° C. Greatest care should be taken that there be no greater variation of temperature than ±5° C. Strict adherence to this limit is essential. Furthermore the rivets, assorted according to equal size, should be brought into the bath in well perforated or wire rivet baskets, in order to ensure uniform heating of the rivets in the middle of the basket. The bath should have a perforated intermediate bottom, lest the rivet baskets or the rivets respectively might touch the heated bottom.

Practical experience suggests the following periods are required for annealing of different rivet diameters:

Rivet diameter:	*Heating time in minutes*:
2-4 mm.	10
5 mm.	15
6 mm.	25.

The rivets are removed from the heating bath and quenched immediately in cold water at room temperature. The time interval between the removal of the rivets

and their quenching should be as short as possible. The shorter the distance or time from the bath to the quenching medium, the better is the quenching effect. Well perforated rivet baskets are also necessary for quenching, in order to prevent the formation of steam in the centre retarding quenching. After quenching, the rivets should be dried and stored secure from moisture. Driving of wet rivets is to be avoided under all circumstances on account of the risk of corrosion involved. For this reason it is better to use air drying plants. When a nitrate heating bath has been applied, it is necessary that any adhering nitrate particles be completely washed off the rivets, in order to avoid corrosion. It is desirable to follow the cold water quenching procedure by a thorough washing in warm water—but not hot—on account of the greater solubility and higher rate of solution of the salt at higher temperatures. The working characteristics in the normal heat treated state vary in inverse order to the physical properties.

When cold driving is made during the first two or four hours after quenching, the rivets remain soft enough. The ageing or hardening process of the rivet material develops at a higher rate only, two to four hours following quenching, diminishing highly the good workability.

(3) Cold forming of the rivets after quenching does not diminish the natural physical and chemical properties of the material and their adaptability for improvement by self hardening, which constitute a special feature of their own. In other words: the forming procedure does not interrupt the increase of the physical characteristics which can be expected when ordinarily stored within four or five days. It has, on the contrary, been proved by latest experiments that by certain methods of cold forming, for instance squeezing, the shear strength of the riveting material is even increased. Recent experiments in plastic forming and ageing of duralumin have shown however that forming accelerates ageing considerably. For duralumin, for instance, it will therefore be preferable to make the forming work *after* ageing, because then the mechanical characteristics are better than with forming *before* ageing. Neither can the heat treatment be repeated to one's liking without infringing upon the mechanical material properties. In order to obtain, in addition to a standard final hardness, a perfectly and regularly timed rise of hardening during repeated heat treatment, it will be better to store the rivets full five days between the different annealings. Experience of the last few years, has shown that in spite of this characteristic of rivet materials of the group of self hardening alloys, which facilitates cold riveting, it is difficult, especially for flush riveting, to obtain the perfectly good flush conditions required for aerodynamic reasons, for the following causes:

(*a*) The increase of hardness following immediately after quenching is, as shown by Fig. 1*a*, after two hours as high as 30 to 50 per cent. One must therefore, even with this space of time, reckon on a steady diminution of cold forming properties of the rivets. This fact alone means considerably higher and therefore heavier claims on the capacity of the working tools.

(*b*) The increase of hardness within the time just following after quenching depends even to a far greater extent too on the temperature of the storerooms or workshops. As shown in Fig. 1*a*, the hardness rises in the course of two hours with a room temperature of 10° C. by about 10 per cent. and with a room temperature of 20 to 30° C. by about 50 or 70 per cent. respectively of the initial value. Differences of temperatures like these must be reckoned with in workshops, according to the yearly average and the season. In consideration of the fact that hardness and shear strength (τ_s) vary in direct proportion to each other, the same reaction for different storing temperatures and periods can be deducted from shear tests made by the DVL, as shown in Fig. 1*b*. If the half round closing head rivet is used, driving tests show that at 35° C. the elapsed time should not exceed half an hour, if one desires to obtain good forming

characteristics ($\tau_s = 25$ kg./mm.^{2}). Rivets driven later show the existence of cracks in the border of the closing head ($\tau_s = 29.5$ kg./cm.^{2}).

These results show how important it is to follow the rule that the time interval for using rivets in good forming condition is decided by the ageing temperature or, which is the same, by the temperature of the shops in which rivets are driven.

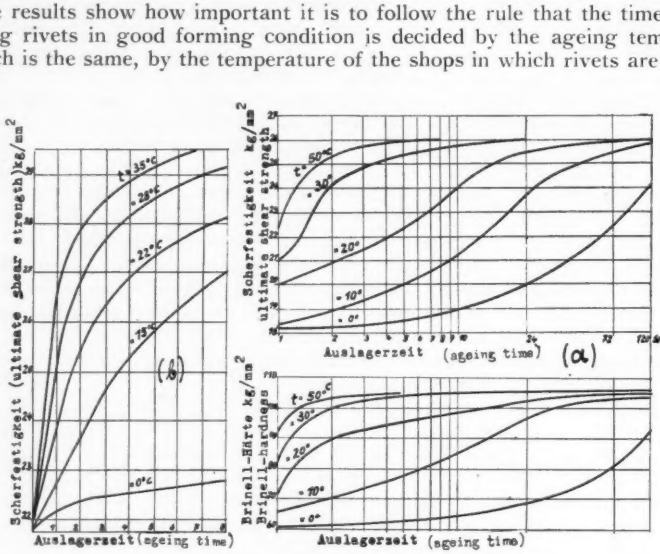


FIG. 1.

Einfluss der Alterungstemperatur t auf den zeitlichen Scherfestigkeitsanstieg von Duralumin (nach DVL-Messungen).

The influence of ageing temperature t on the temporal increase of hardness for duralumin (D.V.L. tests).

FIG. 2.

Due to the fact that the workability in the normal heat treated state varies in inverse order to the physical properties and also owing to the fact that ageing proceeds rapidly during the first two hours after quenching and moreover in a higher degree at higher room temperatures, storing and driving are usually done in Germany within the first one or two hours, and in U.S.A. only half an hour after quenching.

On the other hand, we can see from Figs. 1*a* and 1*b* that by cold storing, or by storing the rivets at low temperatures of about $\pm 0°$ C., ageing can be interrupted or absolutely retarded for many hours. That is to say the period for good workable condition of heat treated rivets can be greatly increased if they are stored cold immediately after quenching, until they are driven. For this reason, freshly quenched rivets are stored in Germany, mostly in low temperature stores or refrigerators (dry ice or solid carbon dioxide) at a temperature of about $-2°$ C., (see Fig. 2), in order to keep them in a workable and soft enough condition for about 24 hours. But the limit of the driving period for these rivets after being removed from the refrigerator is the same as under normal conditions, because when they arrive at normal room temperatures, ageing starts immediately and in the usual way. For storing freshly quenched rivets in dry ice, the following must be strictly noted:

The rivets must be inserted in an absolutely dry state. If they are wet, they will get a thin coating of ice and hurt the workmen's hands when being taken out. Besides they are wet when being fitted into the rivet hole, increasing the danger of corrosion. Owing to the higher cost and the difficulties in organisation, cold storing does, unfortunately, not accelerate production.

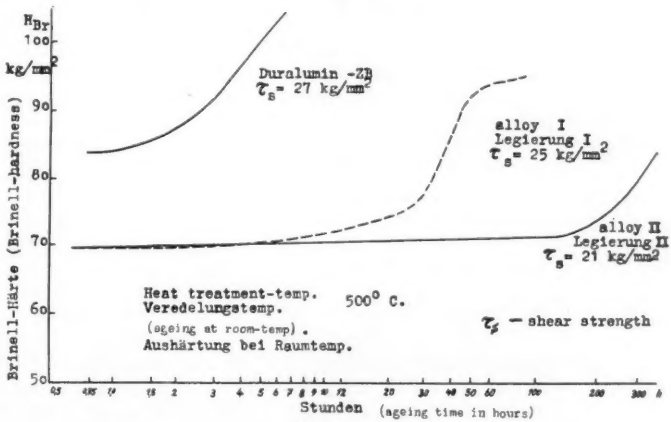


FIG. 3.

Aushärtungs-Eigenschaften von Nietwerkstoffen verschiedener Grundeigenschaften.

Ageing characteristics of rivet materials of different chemical composition.

Among further methods known as successful for prolongation or improvement of good forming characteristics, there is in Germany a tendency to develop rivet metal-alloys for which hardening and the hardening rate at room temperatures is retarded in a higher degree than for the alloys used to-day. In U.S.A. for instance a rivet material A 17 ST is known, for which alloy any increase of hardening starts about 24 hours after quenching only, so that it remains permanently in the same good and constant workable condition during this space of time. On the other hand, the good ductility characteristic of A 17 ST alloy is accompanied by a 20 to 25 per cent. decrease of shear strength. Rivets of A 17 ST, driven in the " as-received " condition, develop an ultimate shear strength of about 18 to 21 kg./mm.² only, against 25 to 28 kg./mm.², which are standard values for the normal self hardening alloys. In U.S.A., however, one is of opinion that strength alone is not the deciding factor. Riveted joints in aeroplane construction will always be over-dimensioned for many reasons, as for

instance: defects in technological manufacture hard to control, particular requirements with regard to riveting seams without gaps or bulges or ridges, considerations regarding standardised rivet sizes and graduations, etc. All these circumstances, for which no exact calculation can possibly be made are the reason why greater rivet diameters and smaller rivet spacings are chosen than would be according to an exact strength calculation. Furthermore, better forming properties of the rivet materials and better characteristics of plasticity in striking eliminate many faults caused by hand driving owing to the human element and ensure a considerably improved uniform riveting-seam and more reliable riveted joints.

We have of late also in Germany such rivet material, the chemical composition of which lies between the ordinary duralumin alloy (4.2 per cent. Cu. 0.8 per cent. Mg.) and the warm hardening alloys and which are distinguished from the former by a lower percentage of copper and a higher one of manganese (2.08 per cent. Cu., 2.10 per cent. Mg., 0.8 per cent. Si., 0.55 per cent. Mn., 0.75 per cent. Fe.). Contrary to U.S.A. practice, a material has been developed in Germany which, similar to A 17 ST, is in a freshly quenched condition softer than duralumin and does not age at room temperature during the first 12 to 24 hours after quenching, the ultimate shear strength of which is however not reduced by more than 10 per cent. when ageing is finished. Fig. 3 shows the characteristic hardness and the temporary increase of hardness of two classes of such material (class I and II) in comparison with duralumin. Use of such slowly or retardingly ageing alloys to a large extent naturally brings a considerable simplification in manufacture. As no ageing starts for at least 12 hours after quenching, the maintenance of the original good forming characteristics is not so limited, and therefore a more regular and shorter riveting-work without bulging is ensured.

(II) Modern Methods of Riveting in Germany's Light Metal Aircraft Construction.

Before speaking on the riveting methods and joints actually in use in Germany, I should like to make the following preliminary remarks:

A. *Reasons Accounting for the Difference Between Riveting Methods in Aircraft Construction and Those of General Engineering.*

Beyond the special peculiarities of riveting in light metal construction just mentioned, which are determined mainly by the nature of these rivet materials, the following reasons may be given as an answer to the question, why the riveting-methods of aircraft construction diverge more or less from those of ordinary engineering.

(1) In most forms of engineering, rivets are driven mainly hot. As they shrink axially when cooling down, there are produced shrinking tensions between the sheets, which as so-called " slide friction " or " slippage " contribute considerably to the ultimate strength of the riveted joint. In light metal aeroplane construction therefore the rivets are, for the reasons already given, driven cold. They fill the rivet holes completely after driving and are therefore subjected mainly to shear stresses, and the walls of the holes principally exposed to bearing or crushing pressures. Tensile stresses should be avoided as far as possible. There are being used at present structural parts of " stressed-skin " construction to a thickness of 1 mm. or less, or in monocoque structures of a thickness of 2 to 4 mm., where the skin sheets are mostly stressed in tension and compression so that a riveting joint in light metal construction and particularly in aircraft construction is subjected to very different stresses. Greatest care in driving and heading is therefore the first requirement in riveting work for aeroplane construction, as only a carefully and exactly made rivet seam or joint will give the guarantee that the theoretical assumptions in strength calculation are realised. When the driving of

rivets is incomplete, the rivet shank will not fill the rivet hole completely as it should do, and when too strongly driven the rivet shanks will cause stresses in the hole walls, as for instance widening or enlarging of holes before riveting is completed, shear cracks at the hole border, etc., which tend to diminish the strength of a riveted joint.

Tests of the strength of riveted aircraft structures, in order to determine the percentage of stress distribution of each single rivet in a multiple row riveted joint, always show that no rule can be deduced from the results obtained. In all cases the cause of this may be assumed to lie in the manner of the technique of driving and heading, which is decisive for the irregular stress distribution to the rivets in a multi rivet joint. This again is caused by faults due to the different ways of hand riveting. I shall refer to this later.

(2) Apart from the quite different nature of a cold driven light metal riveted joint, the physical and mechanical particularities of rivet and structure materials must be taken into account. By equally good use of a riveted joint as to crushing and shear in failure, in order to determine the entire shearing area at a given stress, according to which the number and the diameter of single rivets are to be chosen, the ratio

$$\frac{\text{admissible shear strength of the rivets} \quad \tau_s}{\text{tensile strength of the perforated sheet} \quad \sigma_B}$$

is decisive. However, τ_s/σ_B is at 0.6 to 0.65 considerably smaller for light metal than for heavy metals as iron and steel, which means the necessity of a greater number of rivets of equal cross section for the transmission of the same load for light metal riveted joints than for those in general engineering. As the stress on the single rivet must be proportionately smaller, the ratio of rivet diameter (d) to sheet thickness (s) $= d/s$ in light metal constructions shows higher values than in general engineering, as is shown in Table 1. For this reason, on account of peculiarities in design and of technique in light metal aeroplane construction larger rivet spaces are usual. On account of practical experience space $t = \sim 40\ s$ or $-10\ d$.

(3) The selection of special riveting methods, especially for flush riveting, has furthermore to be made with a view to the necessity for having an aerodynamically smooth surface on the exterior parts which are riveted. Flush riveting has been known for a long time. But in view of the cost of manufacture, which is still very high, this riveting method was used on aeroplanes for special high speed races only, as for instance the British Schneider Trophy racing machines and the first American high speed aeroplanes. Owing to present day high speeds, this requirement of aerodynamically perfect smoothness is necessary to-day and can only be reached if the rivet seam shows no alteration of the original smoothness of the surface. In other words flush riveting is necessary, since rivets heads increase profile drag to a high amount (up to 30 per cent. or more). Flush riveting must be made in such a way that even the slightest bulging and irregularity in the rivet seam are avoided, as they may also increase the drag considerably. This is particularly essential in order to overcome ice-formation near the single rivet point and the dangers associated with it.

Last winter, in Germany, we found that even slight bulging of the skin near the rivet head, especially near the leading edge of the wing, accelerates the formation of ice.

The countersunk riveting methods known from general engineering are not applicable, for the sole reason that thin sheets can very rarely be countersunk with removal of metal from the sheets. I shall give

details how countersunk riveting can be carried out without removal of metal from the hole, later, when I am speaking about flush riveting in aeroplane construction. The application of very thin sheets for " stressed skin " structures and the question of countersunk riveting for them presents, of course, new problems to the work's engineer.

(4) For the selection of special riveting methods the desire to obtain greater riveting strength is not so decisive as the desire to lessen as far as possible the amount of work and cost. The fact that the labour of riveting represents 80 to 90 per cent. of the total time required for structural connections necessary in aeroplane construction indicate that

Bezeichnung identification	Kurz-zeichen short-marking	Abbildung figure
Rundkopf round-head	R	
Flachrundkopf flat round-head	FR	
Flachkopf flat-head	F	
Pilzkopf mushroom-head	P	
Senkkopf countersunk-head	S	
Linsensenkkopf countersunk oval-head	LS	
Flachsenkkopf (120°) flat countersunk-head	FS	

FIG. 4.

Verschiedene im deutschen Flugzeugbau übliche Vollnietformen.
Some solid rivet shapes actually in use in German aircraft construction.

these considerations are worth while. It may be mentioned here that for a Junkers W 34 aeroplane about 200,000 rivets are required, for a three-engined Junkers Ju 52 about 400,000 and for a four-engined Junkers Ju 38 about one million of rivets. A two-engined passenger aeroplane of about 3 to 4 tons in weight (empty) has about 250,000 to 350,000 rivets. It must further be borne in mind that the spaces of time necessary for driving and heading the rivets are considerably increased by the additional working time necessary for drilling holes, for clamping or holding together the structural parts and for the complete removal of drill chips from between the sheets. It will be clear from this that in the development of appropriate methods the main requirement will be

to lessen the work as much as possible. Advantages gained by a small increase in strength may be disregarded when the method calls for an increase of working time. For this reason it is not usual nowadays to form the closing-heads as half-round heads, as the flat closing head or Junkers flat head gives the same strength. The half-round closing head is of greater volume and therefore requires a greater free rivet shank. The considerably greater driving power necessary accounts for the fact that it is not much used to-day. Driving and heading of the half round closing head require more driving blows, the consequence of which is a local augmentation of hardness and a lessening of the quality of riveted joints, for instance by the formation of cracks, weakness as to centring, the risk of damaging the sheets etc.

DIN-Bezeichnung DIN-Classification		DIN - L 71	DIN - L 175	DIN - L 174	DIN - L 177
Setzkopfform rivet head-shape		Rundkopf round-head	Flachsenkkopf countersunk-head	Pilzkopf mushroom-head	Flachrundkopf flat round-head
Kurzzeichen short-marking		R	FS	P	FR
D	f.d= 3 mm	2,0 d	2,15 d	2,33 d	2,25 d
	f.d= 5 mm	1,8 d	2,0 d	2,1 d	
K	f.d= 3 mm	0,7 d	0,33 d	0,84 d	0,5 d
	f.d= 5 mm	0,6 d	0,28 d	0,72 d	
R	f.d= 3 mm	1,06 d	8,0 d	1,24 d	1,8 d
	f.d= 5 mm	0,96 d	7,0 d	1,14 d	

zulässige Toleranz: für d: am Setzkopf: + 0,1 mm; am Schaftende: - 0,1 mm.
tolerance : for d: at rivet-head +0,1 mm; at shankend: - 0,1 mm.
für k: ± 0,1 mm. (for k: ± 0,1 mm.)

Abmessungen der hauptsächlich verwendeten Nietformen.
Dimensions of the rivet-forms, mainly used in Germany.

FIG. 5.

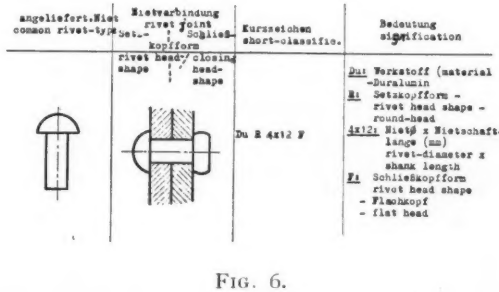


FIG. 6.

B. *The Different Shapes of Riveted Joints in Light Metal Aeroplane Construction and Their Working Methods.*

I must confine myself to a demonstration of those classes of riveted joints and methods among the known methods, for which solid rivets are used exclusively, while the application of hollow rivets is limited to parts subjected to lower stresses or to special cases, where for riveting no accessibility at all or single sided accessibility only is given under certain circumstances.

(1) *Rivets, their Original Shapes and Identifications.*

The original shapes and identifications of rivets used to-day in Germany are shown in Fig. 4. The shapes of rivets are indicated by short mark-

ings, according to their respective head shapes. The round head, mushroom head and countersunk head rivets, their designation to DIN and their dimensions shown in Fig. 5, are the most used rivet shapes after standardisation. To these has of late been added the flat round head rivet, as shown in Fig. 5.

The special manner of representing, designating and giving short markings for rivets or riveting joints respectively, according to material for heads and closing head shapes, to diameter and length of rivets, is set forth in Fig. 6. Such representation facilitates the study of workshop drawings in particular and supplies simultaneously good information as to the way of making rivet joints. Identification marks are also stamped on the heads of the rivets as originally supplied in order to designate the materials they are made of, as in Fig. 7.

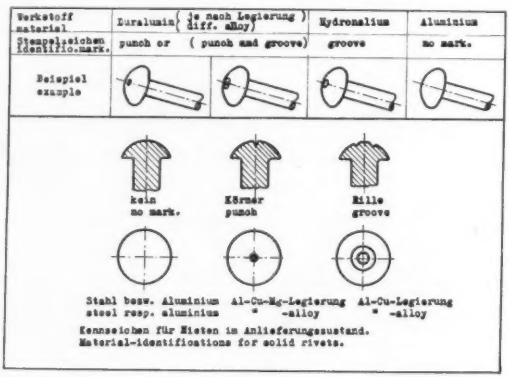


FIG. 7.

(2) *Principles of the Different Stages of Cold-Riveting Operation.*

The main characteristics of riveted joints, the special forms of which will be mentioned afterwards, according to the general rules for their application, are the following:

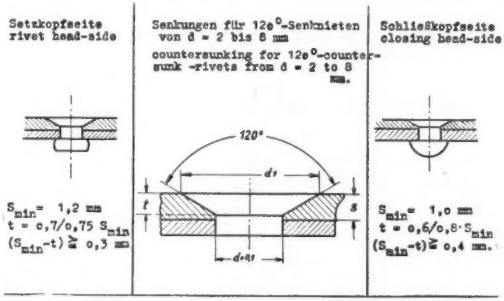
(*a*) Good accessibility to both sides of the rivet to be driven should be provided. Cases of unavoidable restrictions of this and their influence will be dealt with later on.

(*b*) Riveting work requires two men, one to hold the dolly, the other to apply the riveting tool. This requirement is done away with where riveting machines are applied. Actually however hand-riveting with use of portable percussive tools prevails.

The order of operations in riveting work is generally as follows: Drilling and countersinking, insertion and setting up or pulling tight of the rivet, simultaneous or separate so-called " dimpling " of the sheets, and finally, driving and heading. For these operations, unless deviations be necessary, the following general rules will apply: The holes are mostly drilled. The hole diameter d_L will in most cases be 0.1 mm. more than the rivet shank diameter d_N. This clearance is sufficient for an easy insertion of the rivet, the shank of which is already slightly conical towards its free end. The bolt-sided burr of the holes is often removed by the so-called small countersink (radius $r = 1/20 \cdot d_L$). It is understood that all parts to be riveted must be clamped together. Special clamping screws are used for this purpose, particularly for

parts which are accessible from one side only and for quick tightening and loosening of the screw nut. Where long rows of rivets are to be made, clamping should be made at the shortest possible distances, because too great distances will cause stresses in the rivet seam at driving. The holes of the rivet seam should be drilled after clamping only just before the riveting operation is really done. Marking of the drill spots by means of a tracing point is inadmissible, on account of the greater danger of corrosion and the grooving effect.

Countersinking with removal of chips is performed by special countersinking tools which fix the exact depth of countersinking, without risk of damaging the sheets. Rules for the correct thickness of sheets for certain countersinking methods are given in Fig. 8. The general countersinking is, in consideration of strength requirements, applied only



Richtlinien für Senkungen (spanabhebend) in der Außenhaut.
Rules for countersinking skin sheets with removal of drill chips.

FIG. 8.

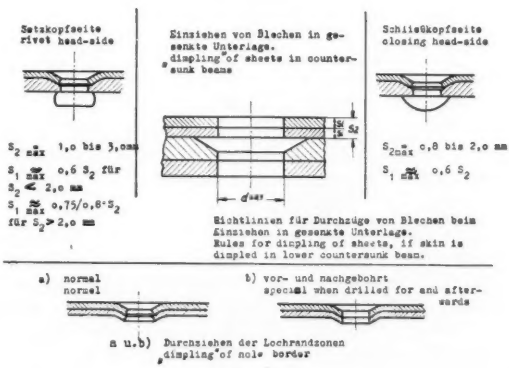

Setzkopfseite
rivet head-side
Einziehen von Blechen in gesenkte Unterlage.
„dimpling" of sheets in countersunk beams
Schließkopfseite
closing head-side
S_2
S_1
S_{2max} 1,0 bis 3,0 mm
S_{1max} 0,6 S_2 für $S_2 \leq$ 2,0 mm
$S_{1max} \approx$ 0,75/0,8·S_2 für $S_2 >$ 2,0 mm
S_{2max} 0,8 bis 2,0 mm
$S_{1max} \approx$ 0,6 S_2
d_{Y+1}
Richtlinien für Durchzüge von Blechen beim Einziehen in gesenkte Unterlage.
Rules for dimpling of sheets, if skin is dimpled in lower countersunk beam.
a) normal
normal
b) vor- und nachgebohrt
special when drilled for and afterwards
a u.b) Durchziehen der Lochrandzonen
„dimpling" of hole border

FIG. 9.

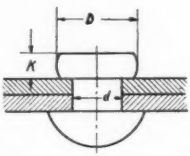
if the thickness of sheets is at least 0.4 of the rivet diameter d_N or, as an absolute value, more than 1 to 1.2 mm. Special regulations have to be arranged for countersinking if only the thick walled inner part of a beam is to be countersunk, as seen in Fig. 9. Driving in or dimpling of sheets near the hole border to Fig. 9*a* is principally a downward draw resulting in a permanently lasting form. Frequently the sheets are dimpled simultaneously with setting up of rivets. For this purpose the setting tool is arranged in a suitable manner. Pneumatic tools being mainly used for

this, the rivet setting tool mostly serves as a dolly. In order to obtain increased regularity of dimpling for skin sheets especially, dimpling of sheets is frequently done by squeezing machines. This, however, requires the sheets to be taken off after drilling and then clamped afresh.

It is a general rule for driving and heading that for riveting with pneumatic percussive tools the rivet set is used preferably as a holder-on. Certain circumstances, as for instance the question of accessibility, etc., may render imperative a deviation from this rule.

Unless the closing head must be given a special shape on purpose, it will be driven as a flat head or a barrel shaped head. The dimensions given in Fig. 10 refer to this shape of head. Recent experiments made in U.S.A. lead one to believe that for rivet sizes of more than 6 mm. and in making use of machine riveting, especially for squeezing, this flat head shape is not so good as the conical shape of closing head shown as cone-

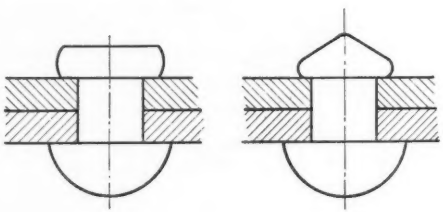
Abmessungen des Flachkopfes.
Dimensions of flat closing head.



	D	K
für d = 2 bis 3,6 mm	1,9 d	=0,5 d
for d = > 3,0 mm	~1,7 d	=0,5 d

Toleranz: ± 0,1 d
tolerance

FIG. 10.



Flachkopf (Tonnenkopf)
flat head or barrel head

Konuskopf
cone point-head

FIG. 11.

point head in Fig. 11. Less power is required for driving and heading at equal strength of the joint. This fact is very important as regards the design of the squeezer and its capacity. Besides it is easier to set a correct and centrally closing head. There is, on the other hand, a correspondingly shaped dolly (not a simple flat one) required, which, however, can be used for several rivet sizes. This special shape of closing head may be preferable for driving thick rivets, because squeezing of thick rivets is often accompanied by the disadvantage that the rivets are not sufficiently guided at driving and often turn out to be eccentric owing to too much elasticity of the machine.

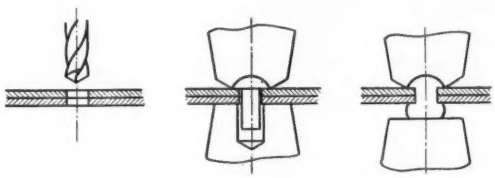
(3) *Different Forms of Rivet Joints.*

Figs. 12 to 15 show the principal rivet joints and their different stages of operation actually in use in German light metal aeroplane construction.

The round head riveting or R riveting with flat closing head shown in Fig. 12, is mainly used for internal structural parts, having more thick-

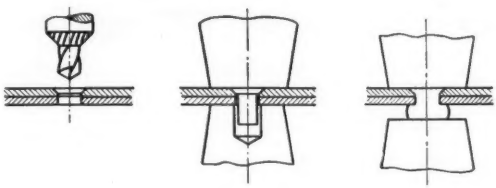
ness of wall with greater rivet sizes, and is also used to a greater extent for skin riveting of water tight floats or boats.

Fig. 13 shows the normal flat countersunk riveting or FS riveting, the application of which for flush riveting is limited by the fact that for countersinking with removal of chips (without a diminution of strength) it is necessary that the thickness of the single sheets on the rivet head side be more than 1.2 mm., on the closing head side more than 1.0 mm. Where one meets with the problem of riveting thin wall skin plates with



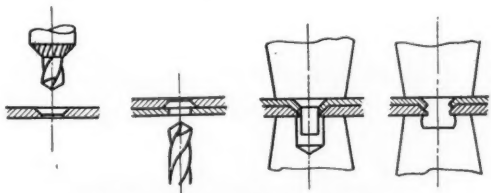
Rundkopfnietung mit Flachschließkopf (R-Nietung)
Halfroundhead-riveting with flat closing-head (R-Riveting)

FIG. 12.



Flachsenk-Nietung mit Flachschließkopf (FS-Nietung)
Countersunk-riveting with flat closing-head
(FS-Riveting)

FIG. 13.



Flachsenknietung mit angesenktem Gurtblech und eingezogenem Hautblech (FS_e-Nietung)
Countersunk-Riveting with countersunk beam and 'dimpled' skin-sheet (FS_e-Riveting)

FIG. 14.

thick wall beams by means of flat countersunk rivets, " dipping " riveting or FS_e riveting as in Fig. 14 should be used. For this proceeding the beam is countersunk with removal of chips and the skin plate is dimpled afterwards. This method is expensive owing to more steps of operation and therefore to higher cost of manufacture.

A more frequent use is made by the methods shown in Fig. 15, as flush riveting is possible with them, namely:

mushroom head riveting or P riveting, and
countersunk dimpling riveting or FS_m riveting.

The P riveting method requires a special shape of rivet heads, the so-called mushroom head rivet, while for FS_m riveting the normal countersunk rivet is necessary. Both methods have been developed and perfected in Germany and are looked upon as being the most modern and in regard to resistance the most adequate riveting methods, especially suitable for flush riveting of thin skin sheets with a thickness of less than 1 mm. They ensure a higher strength of the riveting joint also due to the fact that the natural high shear load of the rivet shank is lessened by an increased bearing or crushing strength. Furthermore the peculiar way in which the rivet embeds itself into the sheet with a slight local

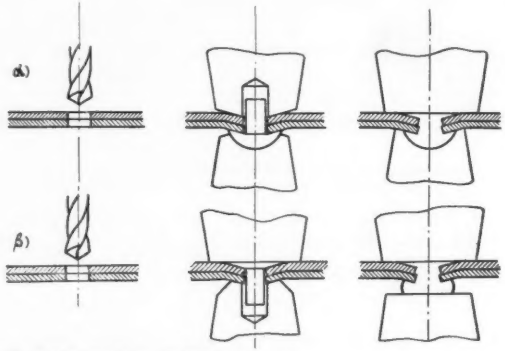
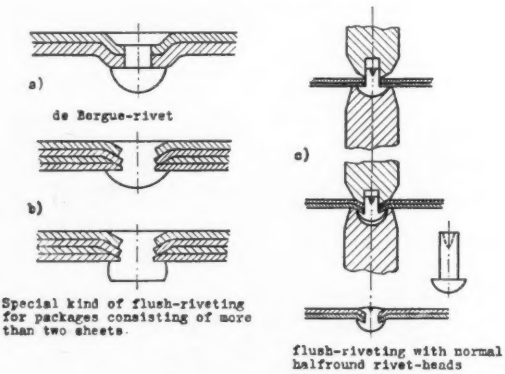


FIG. 15.



FIGS. 15*a*, *b*, *c*.

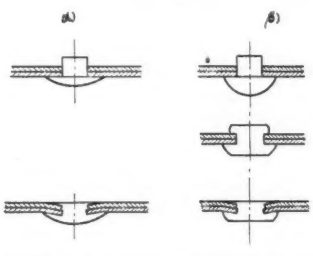
stretching action caused by dimpling produces the effect of overcoming the local spring tensions in the sheets, leaving them in perfect contact. In other words, the local resistance to sheet bending strain is taken advantage of for bearing.

The FS_m method is in principle similar to the De Bergue Patent countersunk riveting process shown in Fig. 15*a*, with the exception that a simple flat countersunk rivet head shape is required for the former. All of the three flush riveting processes have the further common feature

that the special dimpling of sheets is done by the rivet itself when it is pulled tight. Generally it may be said that dimpling is applicable for sheets with thicknesses up to 1.2 mm. and for grips up to 3 mm. It is advisable however to make dimpling separately and not with the rivet itself if the sheet thicknesses approach the higher values. If these maximum values for grips are exceeded, countersinking with removal of chips is possible (beginning at the third sheet, as shown in Fig. 15*b*) also for thinner sheets of smaller single plate thickness than 1.2 mm. but of a greater grip than 3 mm. The top sheets are then dimpled in the usual manner. An experiment made in U.S.A. (shown in Fig. 15*c*) shows that mushroom riveting is possible by application of standard round head rivets. The rivet is inserted from inside; the dimpling of the plates and the simultaneous alteration of the rivet head shape are done while pulling tight, by a convenient shape of snap and dolly. Centre driving and heading are more easily obtained by giving the free shank end a small bore. It should be said however that this rivet is made of a soft material (A 17 ST) of great ductility and plasticity.

From the point of view of workshop costs the P and FS_m methods are very advantageous, as they can be carried out without any increase of cost.

Flush riveting with dimpled holes may be also made by using normal round or flat round head rivets if thin enough, but only slightly stressed



Special kinds of simple flushriveting with half-round rivet heads, applicable to low-strengthening plates.

FIG. 15*d*.

plates ($s \sim 0.3/0.4$ mm.) are to be flush riveted. You see examples of these methods in Fig. 15*d*. The sheets are neither countersunk nor dimpled; furthermore the dolly is flat. By flat driving of the up-setting closing head, the sheets are forced into the rivet head, which is shaped as a mushroom or a barrel closing head. When accurately carried out the strength of this rivet joint will be sufficient, but the application of these methods is limited owing to the fact that no satisfactory control of the quality of the riveting work is possible.

Water tight riveting can be successfully made by both methods if the usual water tight packings are used, and greater rivet spacings than usual allowed.

The FS_m process offers also the great advantage over P riveting that the rivet is inserted from outside and heading is made inside by driving a simple flat closing head. From a view of manufacturing, the following features are of advantage.

(*a*) Insertion of rivets is simpler and easier;

(*b*) Incorrectness in the length of free shanks results only in a somewhat higher flat closing head, without over stressing the hole border of the sheets. At any rate, the aspect and the condition

of the surfaces of the skin sheets in the rivet seam are better. For the P rivet on the contrary, the required rivet snap shape must be strictly adhered to in order to avoid over stressing of the rivet head. Moreover the workman must drive the rivet shank down until a smooth surface is attained, since the closing head is formed outside. If the rivet shank is too long, excessive driving is necessary, which results in an unclean rivet seam.

(C) The rivet being inserted from outside and driving on the rivet head being also from outside, holding on need be flat only from inside. The application of the FS_m riveting method offers undoubtedly advantages also for the simplified use of machine riveting processes. For the P riveting, on the contrary, the striking tool must be set upon the half round rivet head, that is to say from inside of the structural parts. One limit to its application is therefore given by restricted accessibility of the striking tools to the interior of the structural parts.

Further advantages presented by the FS_m riveting method and especially perfection of the working operations mentioned above will be described later when I shall explain the Automatic Riveting Machine.

III. Modern Riveting and Drilling Tools.

I will restrict myself here to give some fundamental views which, according to our practical experience, refer to questions of useful application and handling of tools for light metal riveting.

(1) *Percussive and Holding-on Tools.*

Owing to the custom to carrying out riveting in rather complicated aircraft structures only when these are fitted in special devices, hand riveting still is used. The hand hammer however has vanished. Of all percussive tools 80 to 90 per cent. are compressed air driven hammers. The application of compressed air in aircraft construction to its present extent was possible only after the manufacturers of pneumatic tools had developed special light hammers which proved to be appropriate for aircraft construction. Fig. 16 shows the great economic advantages realised by the use of pneumatic hammers instead of the hand hammers formerly in use. This diagram allows a direct comparison of times required to be made. The respective tests were made in one of our most important aircraft factories, where as early as 1925 the question of application of compressed air tools was the subject of careful study. The time required for riveting with pneumatic hammers being only a quarter of the time required for hand hammer riveting and the cost for riveting work being still considerable in aircraft construction, it is obvious that great economy can be achieved by the use of pneumatic tools. These statements were of course preceded by careful tests concerning the most favourable times for striking types and systems and different ratios of weights of hammers and dollies. I wish to call your attention to the great importance of such investigations. In many cases the cause of bad riveting work and unsatisfactory results obtained by new percussive tools lies in the fact that too light or too heavy hammers have been used. In pneumatic riveting the right proportion of the percussive power or impact of the hammer (number and strength of blows) to the size (mass) of the dolly is of fundamental importance for economic riveting. Hammers of too light weights and with too high a number of blows are frequently used for driving of strong rivet or the proportion of the hammer to the dolly is unfavourable for maximum utility of energy. It should be remembered that the weight of the dolly and its mass distribution to a great extent decide the unavoidable loss of intended forming work through the transmission of energy, because part of the striking tone is used in order to move the mass of the dolly at driving. Tests are to be made therefore to determine for every structural part the most favourable working conditions. It would be a mistake to use light

pneumatic hammers with a high number of blows for driving of strong rivets, because too high a number of blows at low single blow impact produces a more elastic than plastic forming; they tend to peen the head without upsetting the shank. In consequence of this the rivet shank end undergoes much local increase of hardness, if cold driving is done. The failures due to this are: formation of cracks at the closing heads or, later on, bursting off of the brittle closing heads even if riveting joints are subjected to low static loads. It is also obvious that the natural characteristic of workability of the rivet materials have a considerable influence on the result. If the ratio of hammer weights to dolly weights is correctly chosen, the following maximum values can, according to practical experience, be assumed:

(*a*) For riveting with hand-hammers:
number of blows $n_s < 10 \cdot d_N$ (d_N = rivet diameter in mm.) that is to say: for $d_N = 3$ mm., the number of blows n_s should not be more than 30;

(*b*) For riveting with multi-blow pneumatic hammers:
Time of striking (sec.) $t < 1.0 \cdot d_N$, that is to say: for $d_N = 3$ mm., the time of striking should not be more than 3 seconds.

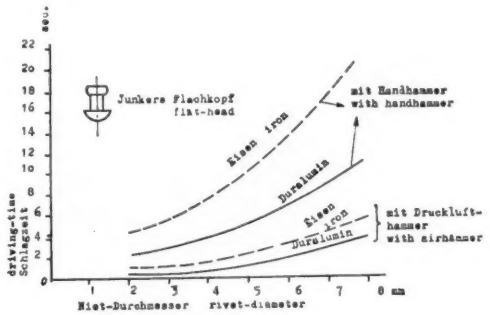


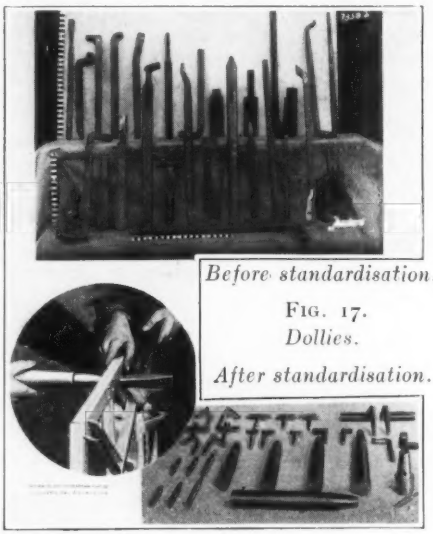
FIG. 16.

During the last few years, flat closing heads have been used exclusively; for these the above values will even be lower. The variety of shapes of structural parts to be riveted often requires considerable deviations from these rules for the best design of dollies, so that a large number of dolly shapes becomes necessary, which means a complication of stock keeping. For this reason, Germany has introduced, during the last few years, a standardising of dollies, specially in weights and shapes with a view to interchangeability of the inserted sets. Fig. 17 furnishes examples of this.

Where riveting must be done on structural parts inside, difficult of access, careful examination as to the most convenient shapes and mass distribution of dollies is particularly essential. Results of such examinations are given in Fig. 18. On account of material stresses, striking time, etc., the minimum weights of dollies for driving of duralumin rivets should not be less than .06 to .075 kg, and for iron rivets not less than .08/.09 kg. per mm.^{2} of the rivet shank section area. The most favourable weights for holders-on amount however to a multiple of these values, and they should always be chosen if accessibility allows of it. Particular care should be taken that the mass of the holder-on be concentrated as close as possible to the rivet shaft which has to be driven.

For flush riveting of thin plates dollies are frequently used with internal springs, as shown by Fig. 19. Elastic embedding of dolly masses prevents the sudden recoil effects of the moving masses and the transmission of vibrations to the structures against which the dolly is supported. By this arrangement permanent

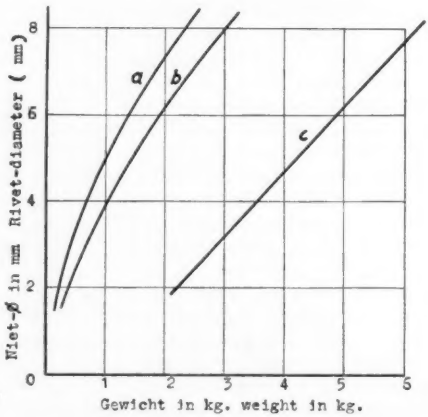
deformations of the supporting parts are avoided. Internal elasticity enforces the effect of masses, that is to say the transmission of energy, and facilitates safe handling of the tool owing to the fact that the vibrations caused by oscillation of masses are located in the interior of the holder-on. Safe handling is, however, required to avoid failures in flush riveting, such as gliding off the rivet head of the dolly and bulging of the sheets round about the rivet hole. As shown by Fig.



Before standardisation.

FIG. 17.
Dollies.

After standardisation.

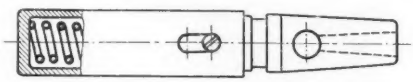


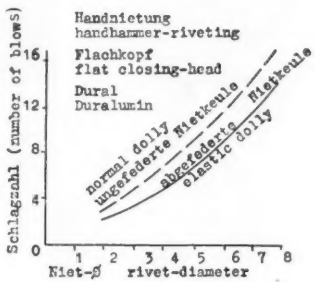
(*a*) *Erfordl. Mindestvorhaltemasse f. Du. Niete.*
Minimum dolly mass required for duralumin rivets.
(*b*) *Erfordl. Mindestvorhaltemasse f. Eisenniete.*
Minimum dolly mass required for iron rivets.
(*c*) *Anzustrebende günstigste Vorhaltemasse.*
Most favourable dolly mass to be desired.

FIG. 18.

19, tools with internal springing allow shorter timed striking. The choice of appropriate dollies is particularly difficult if the shape of the structural part does not allow one to hold the tool exactly at right angles to the surface to be riveted. When cranking of holders-on is necessary the driving-process is rendered very difficult owing to the elasticity and unsymmetrical power effect. The influence of eccentricity on the striking-time and capacity has also been carefully studied in order to determine the maximum admissible cranking of dollies. According to these investigations, the number of blows (a) as a measure of the work required, rises at a nearly linear rate to the eccentricity (e in mm.) in such a way that for a hand-hammer weight of 250 gr. at $e = 0$ mm. to 10 blows, at $e = 50$ mm. 25 to 30 blows are required. This requirement, namely that the dolly must not present any cranking, should therefore be carefully noted at driving.

The majority of pneumatic hammers actually in use belong to the multi-blow class and are particularly suitable to flush riveting. In practice so-called " indirect " riveting has proved to be advantageous, by which the set strikes the





Gefederter Gegenhalter und sein Einfluß auf das Stauchen von Nieten.
Elastic holder-on and its influence on driving-time

FIG. 19.

head of the rivet, inserted from outside mostly, while the holder-on, held against the free shank end, forms the closing head through the motion transmitted by the hammer blow. For this method of riveting the correct ratio single impact to holder-on mass is highly important if the best transmission of energy is to be obtained. Owing to the fact that particularly careful operation of the pneumatic tools at pulling tight or rivets and at dimpling of sheets is necessary, modern multi-blow compressed air hammers are excellent because of their fine regulation of initial blows. They are fitted too with air throttling devices to govern the impact of blows. Fig. 20 shows a series of such multi-blow pneumatic hammers.

For stronger rivets, say for diameters of 5 to 10 mm., especially for structural parts of high rigidity and relatively great extent, pneumatic hammers for slower but heavier blows have proved to be very successful. Slow hitting hammers are preferred where noise is to be reduced. The one shot hammer as in Fig. 21 is the latest product in this line. Contrary to other existing types, this one shot hammer is remarkable because the working piston is loaded, previous to the

commencement of its action by about 60 to 80 per cent. of the full air pressure and that consequently its striking power is higher, although stroke and diameter are the same (driving and heading of a 3 mm. rivet by one single blow). By means of a special governing device the one shot capacity can be regulated over a wide range.

The change over to so-called " open " designs of air frame structures with good accessibility to all riveting points allows the use of such heavy hammers, which are mostly fitted with bows and partly designed as stationary machines,

FIG. 20.

H22Fu. *21 F.* *H19L.* *H19b.* *H19k.* *H17b.* *H18b.* *H17a.*

Multi-blow hammer, type	Total length	Piston φ	Piston stroke	Piston length	Blows per min.	Air consumption (free air at 1 atm.)	For rivets of dural up to ——	Weight
F.M.A.	m/m	m/m	m/m	m/m		m³/min.	m/m φ	kg.
H22F	270	23	74	60	2,100	0.37	9.0	3.0
H21F	250	23	54	60	2,800	0.37	8.0	3.0
H19L	235	20.5	70	36.5	600	0.25	7.0	2.4*
H19b	205		40		2,800	0.30	6.0	2.3*
H19k	191		40		2,800	0.30	6.0	2.3*
H18b	194	20	39	41.5	3,800	0.28	4.0	1.3
H17b	180				3,800	0.28	4.0	1.1
H17a	152				3,800	0.30	4.0	1.1

* If a light-metal grip is used, the weight is diminished about 1 kg.

TABLE TO FIG. 20.

German air hammers for light metal riveting.

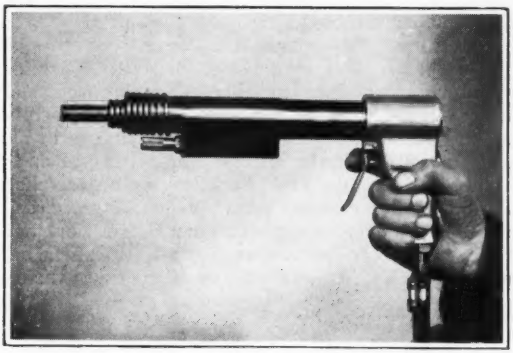


FIG. 21.

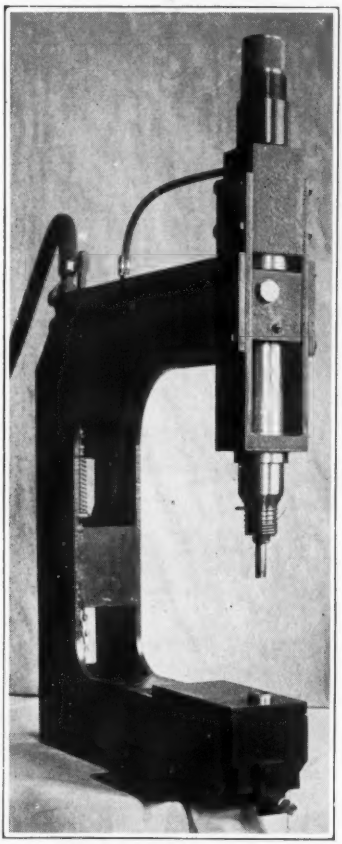


FIG. 22.
FMA-ENM—riveting

partly as portable machines or capable of being suspended by rope tackle blocks with counterweight in order to permit maximum production with minimum fatigue.

A stationary percussive riveting machine of this class is shown in Fig. 22. One man is sufficient to operate it. Percussive riveting machines are in most cases fitted with a sheet clamping cylinder disposed centrally in the hammer axis. Independent separate operation of the sheet clamping device and the hammer is obtained by moving the trigger to a certain abutting point, the sheet clamping and simultaneous pulling tight are effected first. When, afterwards, the resistance presented by the abutment is overcome the hammer starts working. This manner of operation is necessary to prevent working of the hammer before the sheets are securely clamped. In such a stationary or portable design the one-shot hammer

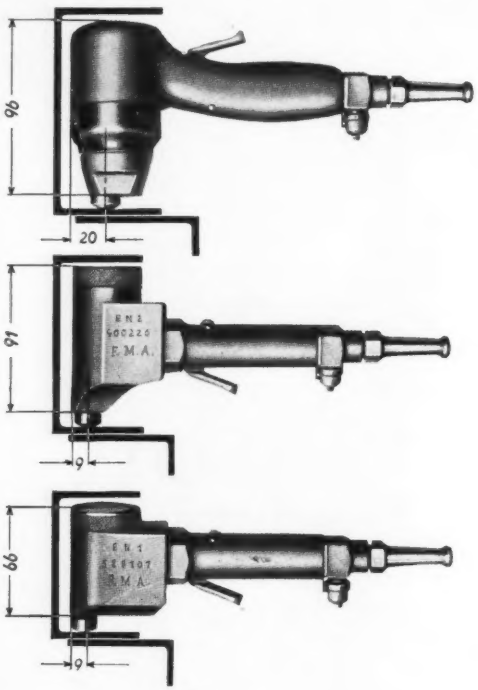


FIG. 23.

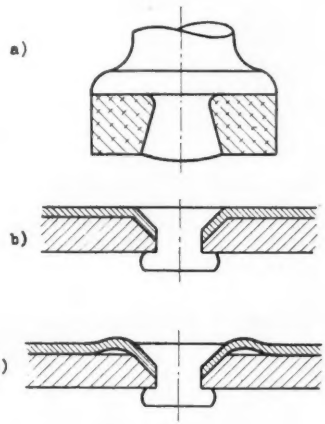
Pneumatic corner riveters, type	Total length	Total height	Piston ϕ	Piston stroke	Piston length	Blows per min.	Air consumption (free air at 1 atm.)	For rivets of dural up to ——	Weight
F.M.A.	m/m	m/m	m/m	m/m	m/m		m^3/min.	m/m ϕ	kg.
EN3	180	96	20.5	38	34	2,900	0.33	7.0	2.6
EN2	166	91	20	33.5	30	4,000	0.20	5.0	1.6
EN1	170	66	25	14	25	5,500	0.28	4.0	1.35

TABLE TO FIG. 23.

German pneumatic corner riveting hammers for light metal riveting.

system as in Fig 22 has been well tried. Apart from sheet clamping a definite closing pressure can be exercised by means of regulating the closing power, whereas with hand operation the closing pressure will vary greatly. One-shot hammers should be preferred to squeezers especially for driving of thin rivets into a thick layer of sheets, that is to say for riveting of structural parts, where, contrary to skin riveting, the ratio of rivet diameter to sheet thickness d/s is considerably smaller than 1.0. Owing to the fact that driving of rivets by means of a percussive riveting machine is performed by a dynamic effect while with squeezers a heavy static pressure is effected, it is easier to design a portable percussive riveting machine of low weight than a squeezer, because the bow for the latter one is too much loaded.

Unfortunately there are still many parts to be riveted for which the hammer tool cannot be used in a normal way on to the rivet. For such complicated work corner riveters have been developed, which by their eccentric disposition of their set are particularly appropriate for riveting work on structural parts near the edge. Pneumatic corner riveters of this class and their dimensions are given in Fig. 23.



a) Döpper für Hautnietung.
Set for skin riveting.

b) Mit Gummiring.
With rubber-ring.

c) Ohne Gummiring.
Without rubber-ring.

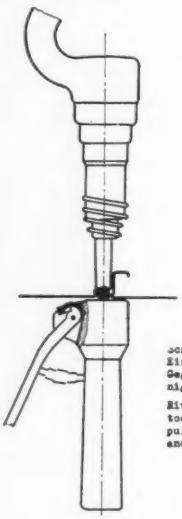
FIG. 23*a*.

Among the special methods for correct application of percussive tools, and more particularly for light metal riveting, I mention the following, which have worked well in practice:

(*a*) Flush riveting, which first of all requires careful handling of the tools in order to avoid damage to the surface, stretching and bulging of the rivet seam. The view presented to the eye by the riveting, varies according to type of riveted joint employed for attaching the skin. The variation in rivet heads, for example in flush riveting, has a marked effect; in mushroom riveting the closing head is on the exterior side of the skin sheets whilst in countersunk flush riveting the " die head " is on the outside. But the main circumstance affecting the appearance is due to the fact that mushroom rivets are closed by internal and flush or countersunk rivets by external hammering. In the first case if the hammer

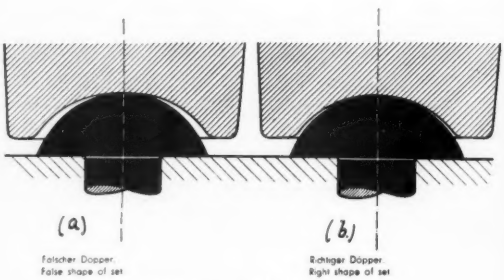
is correctly adjusted, the sheet will retain the correct contour, or possibly may be slightly bulged outward. This is not of the same importance as the drawing of the sheet metal and denting of the skin around each rivet, which occurs with flush riveting in spite of heavy sections and a heavy holder-up. On internally accessible frames and open spar sections, which are too heavy for mushroom rivets, the disadvantages of flush riveting can be avoided by using snap head rivets. The heavy sections, connection fittings, spars, etc., are prepared in the same manner as for flush riveting, *i.e.*, countersunk and the skin drawn in, but the rivet is inserted from inside and closed in the same way as a mushroom rivet; thus adhering to the principle of having one style of rivet in a component and retaining good appearance of the whole line of riveting both internally and externally.

Damage to the sheet skins by flush rivets can be avoided both by large pitches and by appropriate sets.



Schneidwerkzeug mit Einziehwerkzeug und Gegenhalter vereinigt.

Rivet shank-cutting tool combined with pulling-tight tool and with dolly.



FIGS. 24, 24*a* AND 24*b*.

To prevent damage to the skin from sharp edges of the set and marks from the face of the set, even with the set held not wholly perpendicular, flat faced sets may be made slightly spherical on the face with good results. This effect is further aided by a slightly convex face on the die head of flush rivets, although the face becomes flattened during the closing of the rivet. The impact of the air hammer causes the thin dimpled sheet to get chased and bulged. To prevent this effect, a rubber ring is fitted around the end of the set, acting as a sheet holder and thus preventing the development of the buckle (see Fig. 23*a*).

Moreover, by the resistance to resilience of the rubber ring, the set when applied aslant may again be brought in a vertical position, whereby damage to the skin sheet becomes impossible.

The rubber ring acting as a buffer, and also prevents the set being applied aslant.

For flush-riveting, the minimum spacing should be six times the rivet diameter.

(*b*) When the mushroom riveting process is used the usual graduation of shank lengths will in many cases not suffice to obtain a closing head of correct dimensions. If the narrow tolerances of shank length according to standardised graduation be even slightly exceeded, too strong driving will be required if the

closing head is to be on a level with the outer surface. It is to be observed that even the coat of paint between the sheets, and in watertight riveting even more the thickness or elasticity of watertight packages may be of considerable importance already. If owing to this the rivet shank becomes too long, the sheet is exposed to unnecessarily high stretching and bulging. In order to obtain in mushroom riveting a uniform appearance of riveting and consequently cutting to the correct shaft length according to the actual grip after the insertion and pulling tight of the rivet only, one uses in Germany the special rivet-set tool shown in Fig. 24, which combines in it the rivet-set, the cutting tool and the dolly. After pulling tight of the rivet the free shank end is cut to its exact length

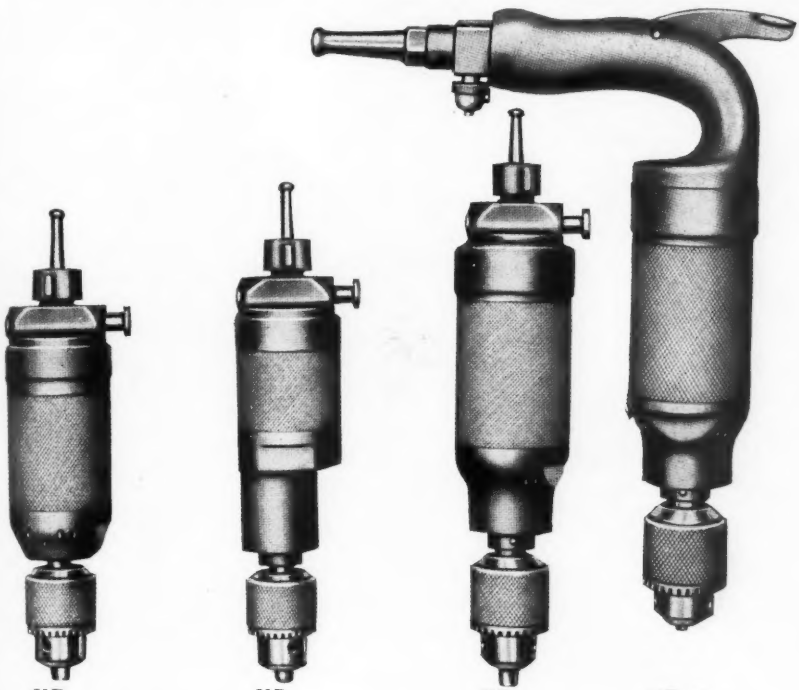


FIG. 25.

Pneumatic drills, type	Total length	Revolutions, unloaded	Air consumption (free air at 1 atm.)	For drilling dural up to —	Weight	H.P. at the spindle
F.M.A.	m/m	U/min.	m^3/min.	m/m ϕ	Kg	H.P.
UR36	240	1,800	0.30	8.0	1.65	0.35
UR1	150	7,500	0.28	4.0	0.78	0.20
UR2	165	3,800	0.28	6.0	0.88	0.20
UR3	195	1,800	0.30	8.0	1.44	0.35

TABLE TO FIG. 25.

German air drills for light metal aeroplane construction.

by the laterally laid-on tongs. After being given a turn by 180° the tool may then be used as a holder-on.

(*c*) For driving of mushroom rivets a special design of the heading tool is required. If a set similar to Fig. 24a is required, as it is usually used for normal half-round head rivets of same contour, the mushroom head with its thinner head border or head edge would change its shape under the effect of the first blows in accordance with the wider shape of the heading tool. Owing to this fact the rivet head border would become over stressed and tend to crack. On account of this, mushroom riveting requires a heading set, as shown in Fig. 24b. It embeds the rivet head very closely. Its depth should be about 0.3-0.4 mm. less than the height of the rivet head. By means of this heading tool normal half-round rivets can also be well driven. This allows a combination of the heading tools and a simplification of tool storing.

2. *Drilling Tools.*

Holes for light metal constructions are usually made by drilling, not by punching. The modern development of pneumatic drills with their economical and mechanically simple drive by means of rotary motors has made such a progress that pneumatic drills are more and more being given preference over electrically driven drills, especially for smaller capacities as required in aircraft construction.

Among the many advantages presented by pneumatic drills are the following:—

(1) Safe application, especially in workshops containing explosive mixtures of petrol.

(2) By jamming, for instance owing to too high pressure, the rotor simply stops, the air supply is interrupted and no breakage of drill shanks owing to overloads can occur. It should be pointed out that the consumption of drilling steels is a very important economic factor.

(3) The pneumatic drill is of considerably smaller dimensions and its capacity weight is much smaller, namely, one-third only that of an electric drill. It is therefore easily handled.

(4) Great elasticity of drive is ensured by throttling of the air supply, and by gradual admission of air slow up starting as well as speed governing in a wide range are possible, without any diminution of the torque.

(5) Smooth running without vibrations renders it particularly suitable for light metal construction.

For these reasons many German aircraft manufacturers now use pneumatic drills exclusively. Some types of such drills, which have been developed particularly for this manufacture, are shown in Fig. 25. For drilling capacities of from 2.0 to 8 mm. in light metal the weights range between 0.8 and 1.6 kg. As for drilling in aluminium alloys the rate of feed should be small (0.5-0.1 mm.) whereas the cutting speeds may be very high. The speeds of these drills (4,000 to 7,000 revs. p. min.) are very near the most economical speed values. However, it should be mentioned that for drilling of aluminium alloys drills of special design with little pitch and favourable cutting angles are required, as shown in Fig. 26. Only with these smooth walls, holes without burr and good ease cutting can be attained.

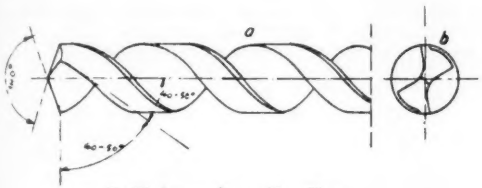
By drilling into thin sheets the surface may get damaged by the rotating chuck if owing to too high pressure applied to the drill the drill suddenly breaks through the sheet. By putting a piece of rubber hose on the drill (Fig. 27) this danger is avoided.

For drilling on structural parts of little accessibility or of little height, say 15 to 20 mm. and a minimum of edge-distance, say 7 to 8 mm., special corner drills have been developed, as shown in Fig. 28. An advantageous arrangement has been designed for this; the normal drilling machine can be coupled with an interchangeable special corner device, by means of which the standard drill can be

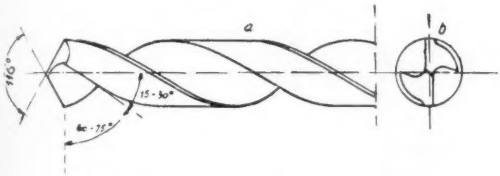
transformed into a corner drill and storekeeping simplified. Such corner devices are supplied in different lengths.

The application of compressed air gives, moreover, the possibility of catching all drilling chips by suction. Fig. 29 represents a drilling machine with a special device for chip suction. Suction of chips is desirable for the following reasons:—

(1) The necessity of removing chips from between the sheets requires a further disconnection of the sheets after drilling. For drilling of surface protected sheets loose chips are bad as these surfaces are very liable to



Drill for softer Al. alloys.



Drill for harder Al. alloys.

FIG. 26.

FIG. 27.

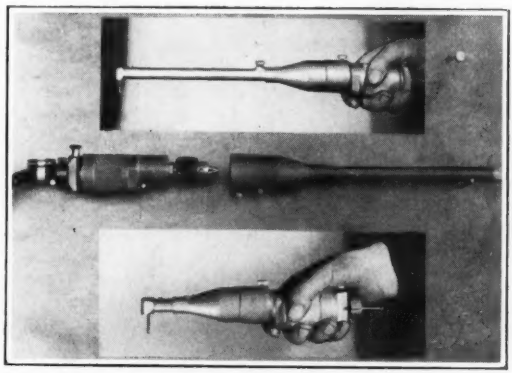


FIG. 28.

damage. It is for this reason that tools and tool boxes in workshops when placed near such structural parts are fitted with felt layers. This danger is absolutely avoided where chips are removed during drilling by suction.

(2) If structural parts are accessible from outside only, chips must at any rate be removed during drilling.

(3) By drilling of structural parts with watertight intermediate packings, the chips often form a rim round the border of the wet watertight packings between the sheets, which renders it difficult to obtain absolute tightness of riveting.

The chips are sucked into a box, which must be emptied from time to time.

IV. MACHINE RIVETING.

The question whether or not machine riveting can be applied is decided by the solution of two problems:—

(1) Such riveting machines with given dimensions must be applicable to existing designs of structural parts to be riveted, or

(2) The structural parts to be riveted must *a priori* be designed with a view to such application.

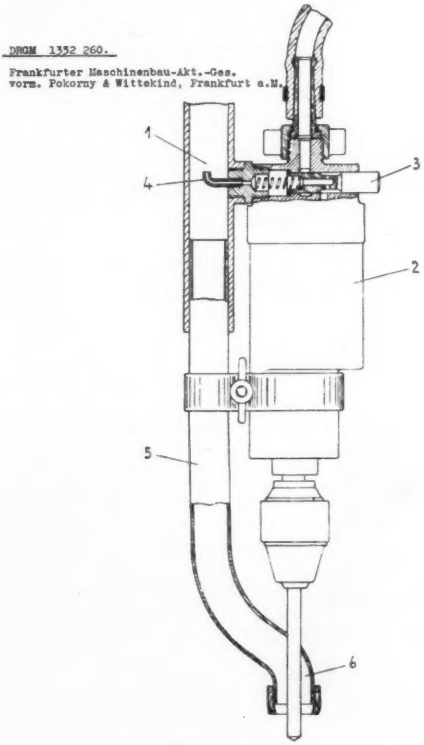


FIG. 29.

There have, during the last few years, been more and more adopted in aircraft construction so-called " open " designs with accessibility from both sides, and a steadily increasing demand for portable or stationary riveting machines has followed. The majority of existing machines serve, however, exclusively for driving and heading of rivets. The weights of all these machines are relatively high, and they can therefore be used only if suspended. These high weights are mainly due to the bows of these machines, as they must be of a solid and rigid design, especially if the riveting machines are squeezers. As already mentioned, the one-shot or single-blow system has proved to be of great advantage, because

the driving effect and transmission of energy from the percussive tool is brought about rather by dynamic effect. By the application of such machine tools a better utilisation of energy is attained and furthermore a uniform adaptability of operations to the respective structural conditions and an improvement of the riveting work in its technique.

Modern aircraft, however, is already past this stage of design development. Our actual light metal construction types require more rapid and low cost production in riveting, and better and more uniform riveted joints than formerly. We are therefore much interested, especially for rapid quantity production, in appropriate automatic riveting machines capable of performing automatically all operations required for riveted joints. To explain this, I would like to give the following arguments:—

(1) As the riveting joint in light metal construction and its special features, namely, that the rivets are driven cold, that the structural parts be connected by riveting undergo greater and other kinds of stressing than those met with in general engineering, aircraft riveting requires a more accurate carrying out of the rivet seam, this being the first preliminary condition for the attainment of maximum strength. Tests made in this direction have shown that the technique of riveting is of considerable influence on the rivet load distribution in a riveting field. So long as riveting is made by hand, we must reckon with the fact that the rivet loads are distributed in an irregular manner on so thin-walled structural parts as aircraft construction uses them, and that the force acting on any individual rivet loads cannot be brought into definite rules. The shortcomings of technique have been mentioned already. Besides this we must take into account human error. The expenses of a careful supervision are rather considerable. Owing to these facts, considerable margins must be assumed in theoretical strength calculations. Economic utilisation of riveted joints in light metal construction is therefore significant. Many failures can be avoided by automatic machine riveting, as this method guarantees the highest degree of workmanship.

(2) So long as riveting is performed by hand, the proportion of the cost of work in the total cost of manufacture of aircraft is considerable. Apart from the advantages lying in the simplification of working methods, checking appliances, and the diminution of work to be done, machine riveting ensures a notable decrease of these working costs, which hitherto have been the greatest factor in the aircraft manufacture and which can be reduced only by a considerable extension of machine riveting methods.

Comparative tests made in a German aircraft factory, for stressed skin structural parts fulfilling equal strength conditions designed *a priori* in a manner appropriate for automatic machine riveting, have shown that the cost of riveting can be reduced to only 40 per cent. of the former cost figure.

(3) The present development of aircraft designs shows a steady increase of the adoption of stressed skin construction, the main feature of which is that the skin consisting of thin plates of 0.4 to 1.0 mm. thickness is reinforced by many longitudinal and transversal compression stringers. Examples of different stressed skin designs for wings and fuselages are given in Fig. 30. In order to obtain simple and rapid manufacture, such a so-called monocoque construction is divided in several parts, which are built separately and then assembled. For aerodynamical reasons, flush riveting only can be used for this. Such stressed skin parts are generally remarkable for their simple design, for " open " elements used to a wide extent, for long and uniform rivet seams, and for uniform rivet dimensions and spacings.

In stressed skin construction the riveting work constitutes a considerable part of the working hours. For a modern monocoque fuselage of " stressed skin "

construction, for instance, this portion of cost, including supplementary work such as drilling, holding the sheets together by means of bolts, removal of drill chips from between the parts, etc., amounts to about 35 per cent. It will therefore be understood that the question of cost for riveting becomes more and more important. The question: "In what way can riveted joints of stressed skin parts be designed more properly in order to simplify the problems of manufacture?" is to-day a vital one for the aircraft engineer.

D.V.L. investigations on the influence of rivet spacing t on the compression strength of thin stressed skin parts of duralumin, reinforced and slightly curved, with a medium skin thickness of 0.74 mm. and with an even amount of cross-sectional distribution to skin and longitudinal stringers, have given the fol-

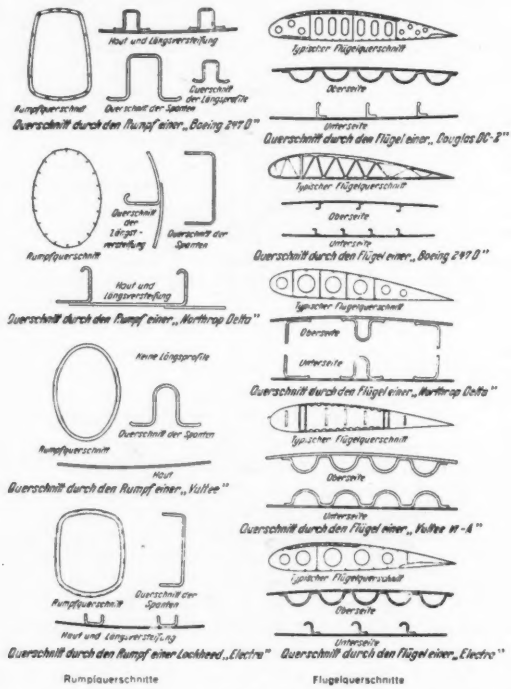

Haut und Längsversteifung
Rumpfquerschnitt
Querschnitt der Spanten
Querschnitt der Längsprofile
Querschnitt durch den Rumpf einer „Boeing 247 D"
Querschnitt der Längst-versteifung
Querschnitt durch den Rumpf einer „Northrop Delta"
Kleine Längsprofile
Querschnitt durch den Rumpf einer „Vultee"
Querschnitt durch den Rumpf einer Lockheed „Electra"
Typischer Flügelquerschnitt
Oberseite
Unterseite
Querschnitt durch den Flügel einer „Douglas DC-2"
Querschnitt durch den Flügel einer „Boeing 247 D"
Querschnitt durch den Flügel einer „Northrop Delta"
Querschnitt durch den Flügel einer „Vultee V-1 A"
Querschnitt durch den Flügel einer „Electra"
Rumpfquerschnitte
Flügelquerschnitte

FIG. 30.

Stressed skin construction of aeroplane wings and fuselages.

lowing result: If the rivet spacing t is increased from $t = 20$ mm. $= \sim 7\ d_N$ to $t = 70$ mm. $= \sim 23\ d_N$, the load carrying panel width of the skin is decreased to about 50 per cent. With an increase of t to about $t = 7\ d_N$, the amount of this decrease is a linear function of t. Only a sufficiently narrow spacing of $t = 5$ to $7\ d_N$ prevents absolutely bulging of the skin near the longitudinal stringers between the rivets, that is to say, the skin is fully stressed. Greater rivet spacings cause the skin between the rivets to bulge more and more near the longitudinal stringers, owing to the fact that the elastic elongation of the skin is smaller than that of the adjoining string of longitudinal stringer. Similar results have been arrived at from tests made by the California Institute of Technology, reported by W. Howland. In consequence of this the tendency will

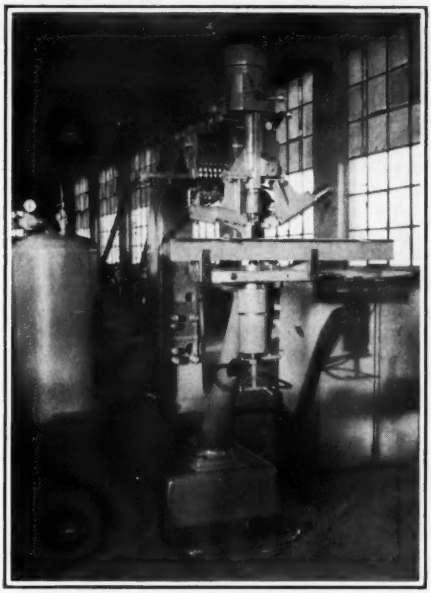


FIG. 31*a*.

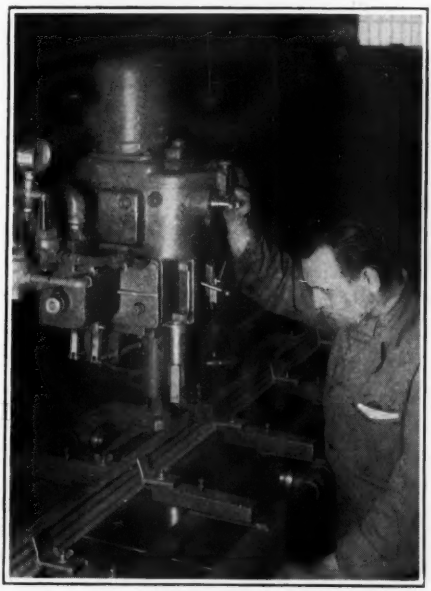


FIG. 31*b*.

be to use smaller rivet spacings for stressed skin structures than actually in use with $t = 40$ s.

For these reasons the following can be said: Owing to the fact that the strength of the skin is relatively high, seams and laps must be riveted with narrow spacings. As the diameter of rivets is no more than 3 mm. mostly, and as the inner stiffeners of the skin must be riveted near to each other, the number of rivets to be inserted into the skin will be the higher the more the skin is designed for aerodynamic reasons, and for the transmission of stress. Machine riveting saves a considerable amount of time, especially for riveting of stressed skin parts.

Availing myself of this opportunity, I beg to be allowed to give a detailed description of a German automatic riveting machine, namely, the F.M.A. automatic riveter, which will be more fully and better illustrated by the film which I am going to show.

This apparatus (Figs. 31*a* and *b*) has been developed in close collaboration with German aircraft factories—the first stage of development is done by the Henschel-Flugzeugwerke—and is therefore up to the particular requirements of modern aircraft construction. It performs successively all operations required to make a riveted joint, such as drilling, countersinking with removal of chips or "dimpling" of sheets respectively, rivet holding and insertion, driving and heading—all in

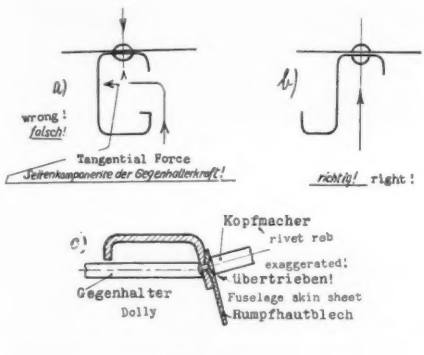


FIG. 32.

one vertical axis. Details of the arrangement and function of the automatic riveter can be noted from the film. I only wish to point out that the chips generated at drilling and countersinking are at once blown away by compressed air, and that cooling is effected during drilling, which is necessary for certain alloys, as for instance electron.

Needless to say, for a comprehensive application of automatic riveting machines, in order to save cost of manufacture, parts should be designed so as to accommodate themselves to the special disposition of such machines. Many of existing designs are inappropriate for this, while others, thanks to their simpler structure, allow of quicker production, without restriction of requirements regarding strength. Among the mistakes most frequently made, we find the following: Neglect of the question of both-sided accessibility to riveting places, insufficient possibility of driving rivets centrally, etc. I show in Figs. 32 *a*, *b* and *c* a few instructive examples. The design of one of these parts does not observe the rule that at driving and heading the holder-on must be set up in shank axis and vertically to the surface. The special design of the other parts requires even cranked holders-on, giving a tangential force acting on the rivet head and therefore slanting of rivet heads. The next shape, however, shows in what way this fault can be avoided, namely, by choosing a more suitable shape of stringers, without restriction of the original purpose. Unfortunately there can, in aircraft

construction, be found plenty of examples of independent designs, careless of riveting practice, due to which the insertion and even more driving of rivets is difficult. More instruction will be required to make the designing engineer so familiar with the questions respecting low cost manufacture that he will be able to build the details of structures according to requirements for rapid production. We find ourselves still at the beginning of an economic development of aircraft construction, which requires a close collaboration of the designing office and the workshops. It is, however, necessary for this that the designing engineer be fully acquainted with modern methods of economic production.

V. Final Remarks.

Finally, I should like to make the following remarks:—The riveted joint will be the most useful permanent connection in light metal construction. At present, however, the practice of riveting is still very difficult owing to the fact that the structural members vary too much and that furthermore many designs, though novel in construction are not good from the points of view of economy. The designer must be given clearly to understand that the first conditions of exact strength calculations for riveted joints are fulfilled only if clean riveting work is really ensured in practice. However, it must be the task of workshop people to do away with faulty design, by devising precision tools facilitating riveting work heedless of cost.

Many German aircraft factories are already bearing this in mind and have issued clear regulations aiming at a close collaboration of designing office and workshops, all the more indispensable where locally separated branch factories are building similar types of aircraft under licence. Considerations as to the best use and treatment of materials, the most appropriate design of structural elements with a view to economy and working processes available will therefore have to be studied and decided by the " experimental manufacturing work." This department will issue definite and strict rules as to the course to be taken in manufacturing. The officers of the developing department already exercise their influence when the designs are in their nascent state. Thanks to their continuous advice the designer is enabled to take advantage of their practical experience when drawing out new designs. In order to facilitate teaching of unskilled workmen, " riveting schools " have been established in Germany.

The problems which present themselves to the aircraft engineer to-day are therefore more numerous than they ever were, the more so as the questions of economic manufacture are actually predominant. In addition to the problems connected with general engineering, the aircraft engineer has to fulfil further requirements owing to the facts that an aeroplane must also be designed aerodynamically perfect and be light of weight when empty. The final aim of development must be to-day that all parts be laid out in a manner to require a minimum of time and of cost for manufacturing.

As far as riveting methods are concerned, I hope that my lecture will contribute a little to solve these problems.

Discussion.

The Chairman: Everybody had been fascinated by the lecture and pictures and he proposed to call for discussion upon them before expressing the thanks of the meeting to Dr. Pleines. As time was short, he asked speakers to be as brief as possible and added that written contributions to the discussion would be welcomed. He also intimated that Dr. Pleines would reply in detail in writing.

Mr. F. Handley Page (Vice-President): There were one or two questions he would like to ask. The author had not dealt with the riveting of tanks. Mention had been made of water-tight joints, but many people were interested in petrol-tight joints, and therefore he would like to have some further information with regard to modern practice in Germany in that respect. It would also be useful

to know how many rivets of the ordinary type and how many rivets of the De Bergue type were used and what kind of jointing material was preferred.

Another matter on which further information would be of interest was with regard to tanks which were part of the wings themselves. In that week's issue of *Flight* or the *Aeroplane*—he was not quite sure which—there was a description of a barrel type of tank which was part and parcel of the structure, and it would be interesting to have further information of tanks similar to the ones now being made in America in which both walls of the spars and the top and bottom of the tank were top and bottom surfaces of the wing, and it would be interesting to learn from Continental practice how to keep such a tank petrol-tight.

Major WYLIE (Fellow): The lecture had dealt so completely with the subject of solid rivets that his own first impression had been that there was nothing more to be said. The illustrations of the mushroom head rivet and the dimpling of the sheets into this type of rivet head were extremely interesting, but a point to be borne in mind was that mushroom head rivets must be inserted from the inside. Rivets sometimes fell instead of entering the intended hole, and it was a great deal of trouble getting rid of rivets which had dropped inside the structure. It was preferred in this country, he believed, to use rivets with countersunk die heads which were inserted from the outside.

Many of the difficulties with solid rivets, such as the stretching of the holes into which they were inserted, had been overcome in this country by the use of hollow rivets pressed from sheet metal. Hollow rivets have been further utilised because in the form known as Pop rivets they are inserted and driven entirely from the outside. The driving is effected by a pin which passes through the bore of the rivet, and in one form this pin has a flat head which breaks off after it has compressed the rivet and formed the driven head. The breaking strength of the pin is accurately controlled in manufacture so that the rivet is pulled up to the right amount to fill the hole without stretching the sheet metal when the head breaks off. It would be interesting to hear what was being done in Germany in that connection.

Another type of rivet which many people here would like to hear something about from the author was that which was known as the shot or explosive rivet, recently described in the *Aeroplane*, which stated that a charge of gunpowder accurately proportioned to the length and diameter of the rivet, closed the rivet with great accuracy and gave an efficient joint.

Note.—In his reply Dr. Pleines said that hollow rivets were not used in Germany because they were not so strong as solid rivets. The answer to this is " that where the hollow rivets require to have the strength of solid duralumin rivets they are of nickel alloy. This material is uncorrodible, but is cadmium coated so that it may not promote corrosion in aluminium alloy, with which it may be in contact."

Mr. W. C. DEVEREUX (Fellow): Notwithstanding the large amount of information contained in the paper, he felt the author could say a great deal more with regard to actual material. For instance, he was wondering what had been done in Germany with low copper material.

It was stated that the annealing of rivets was carried out with a constant temperature of about 505°C., and that care should be taken to see there was no greater variation of temperature than ± 5°C. It would be interesting to have some information as to the alloy used at these temperatures because it was getting rather to what they considered, in this country, to be the danger temperature. In this connection he thought it worth while mentioning the use that was made of the terms " annealing " and " normalising." It might be a translation error, but these terms seemed to have been borrowed from the steel industry and it should be made clear that they were an entirely different thing in the case of aluminium. There was a difference between annealing and solution treatment.

Finally, Mr. Devereux said that having studied the development of riveting in Germany very closely, he felt there was something more in it than devising

methods of riveting; a great deal had also been done with regard to the self-ageing of alloys in riveting. With regard to the explosion rivet, he said he understood that the temperature required for the explosion caused the rivet to contract away from the structure when cooled; he would be obliged if the author could give any information.

Dr. H. SUTTON (Fellow): The paper was extremely interesting. There was a very large amount of information in it and he wished to pay his tribute to the author, in addition to that of previous speakers, for the paper was a valuable addition to the somewhat scanty literature in this country on riveting light metal construction.

They owed it very largely to Germany that they had such a useful series of alloys of the aluminium-rich magnesium type. The author had referred to another interesting alloy which had a lower percentage of copper and a higher percentage of manganese than duralumin, and it would be interesting to know whether that alloy was likely to displace duralumin as a rivet material. There had been enormous use of what they called MG 7 in transport industries other than aircraft in Great Britain, but in aircraft applications they in this country had not gone as far as they had in Germany with that type of alloy. Therefore he would like to know whether the alloys in question were proving very useful as rivet material. Their high corrosion resistance was outstanding, and the author had already referred to them as being used for rivets in elektron. Some preliminary experience gained in this country suggested that strength properties comparable with those of duralumin could be obtained with MG 7.

The flush or countersunk rivet had an advantage from the corrosion point of view, and that was a matter which interested him personally a great deal. With this form of rivet, the material seemed to be more concentrated. The shank of the rivet was shorter, and, with the countersinking or depressing, one would expect to have less relative movement about the rivet itself; it was, perhaps, fortunate that the present tendency of design was in the right direction to improve matters from the corrosion point of view.

Finally, Dr. Sutton asked the author whether there was any tendency with the single punch method of inserting the rivet to leave undue tension in the shank.

Mr. D. L. HOLLIS WILLIAMS (Fellow): He expressed the view that it should be a matter for reproach that a process which occupied such a large amount of labour in the construction of aircraft should have received so little research in this country. Therefore, a great debt of gratitude was due to the author for his work. Speaking of the relative advantage of feeding the rivet from the inside of the structure or from the outside, he said it seemed that if the rivet was fed from the inside there was the problem of having unprotected metal outwards where a bright metal surface might be desired. If, on the other hand, the rivet was fed from outside, then the formed head was on the inside of the structure and could be protected by normal painting methods.

Mr. H. DAVIES: To what extent was electric spot welding used in Germany and for what parts was it used? Had it been found to give reliable results in the main structural parts of aircraft?

Mr. RADCLIFFE (Associate Fellow): He would be glad if the author would confirm that the automatic riveting machine of the F.M.A. was capable of handling various lengths of rivets of the same diameter with the same holder, and whether there were available different holding heads for different diameters which could be rapidly adjusted for use with the machine. Further, was there ready adjustment for getting different degrees of hammering from the lower working piston to meet the various requirements met with in the shops?

The CHAIRMAN: He had been rather disappointed that more questions had not been asked with regard to this paper, but that was partly due to the very complete information which the author had already given. There were, however, one or two remarks which he himself would like to make. One was with regard to the cost of aircraft construction. The cost of aircraft construction, in very rough

figures, was about £1 per lb. On the other hand, the most expensive motor cars cost about 5/- per lb., whilst the type of motor car most people could afford cost a very few shillings per lb. In pre-war days some cargo steamers were built for about 1½d. per lb., so that the comparable cost of the light metal construction which the author had described, using, as it did, large quantities of man power, was a thing to be thought about very carefully. The author assumed—no doubt it was right as the author knew much more about the subject than he himself did—that he must use large quantities of rivets and that the tendency was to increase the number of rivets. With some types of construction it was being found necessary to use plates of considerable thickness, and he would have thought that designers should be urged to design in such a way that the number of rivets was cut down. Some comments on that matter would be useful.

Another point which had appealed to him was the systematic way in which the author had investigated this matter; apparently most of his conclusions were carefully reasoned from experiment, and this made the paper all the more valuable.

In the paper the author spoke of the necessity for flush riveting all over the surface of the aeroplane, but so far as they had gone they were not clear that flush riveting at the back end of the wings was necessary. Mention was made in the paper of an increase of profile drag amounting to 30 per cent. due to the rivet heads, but he would like to know a little more about that figure, which seemed to him to be very high.

There was one other matter in connection with flush riveting. In a good many military aircraft the fuselages were badly shaped for military reasons and it did not seem to be very necessary to go in for the refinement of flush riveting when there was a bad structure from other points of view. If the author would care to comment on that, it would be interesting.

Although the author had dealt solely with riveting, there was a great interest in welding, and for certain purposes he imagined that welding would compete with riveting. He was specially impressed by the films showing the automatic riveting machine and would have liked to have seen more of that, though all the paper had been of exceptional interest. It had all been a great treat, and he asked the meeting to express its appreciation of the paper in the usual way.

The vote of thanks was carried with hearty acclamation.

Reply to the Discussion.

Replying to the question of *Mr. Handley Page* about the German riveting methods for water- and pressure-tight tanks, for a number of years we have used in Germany aluminium successfully as a material for tanks. Jointing of the metal sheets is done by autogenous seam-welding only. It therefore was particularly interesting to me to find during my visit to English aircraft factories that the use of high-strength Al. alloys of the dural-type has been developed to a large extent for tank building, using the special countersunk riveting methods of De Bergue. In the German aircraft industry there are tests being made on riveted tanks of similar alloys. I am, however, not in a position yet to say anything about the results of these methods and those obtained with certain jointing means, because I have so far not received any test values.

With regard to the further question whether integral tanks, *i.e.*, tanks which are part of the wings themselves, have been developed and used in Germany, I would refer to the tubular spar-wing construction of the Hamburger Flugzeugbau, which may be known also in England from German literature, for which design the inner wing spar has also been developed as a tank. This tubular spar is made of steel, however, and consists of two thick-walled halves which are connected by seam-welding. Special jointing is therefore not required in this instance, the welded tubular spar ensuring an absolutely safe storage of the fuel. The spar dimensions are large and it was possible to store, without any risk of leakage, 6,500 lit. of heavy oil in the DLH—long distance—seaplane H 139.

I fully agree with *Major Wylie* that the use of mushroom head rivets is, from a practical point of view, less favourable than the countersunk dimpling-riveting or FS_m-riveting, since the mushroom rivet must be inserted from inside. As pointed out in my lecture, FS_m-riveting is for this reason being more and more preferred in Germany.

Several causes have determined the use of hollow rivets and the development of appropriate hollow riveting methods in the light-metal aircraft manufacture in Germany. For the manufacturer, riveting with hollow rivets affords the possibility of joining parts of single-sided accessibility and to have the work done by one man only, instead of two usually required. The problem could, however, not be solved without the use of special tools.

From the point of view of strength it is an obvious advantage to use hollow rivets instead of solid rivets. In light-metal construction the admissible value of crushing strength σ_L of the metal sheets is approximately 2.5 times the shear strength τ_a of the rivet material. The crushing surface required, increasing directly with the rivet diameter d_{N1} the shear cross section area of the rivet, however, with d^2_N, it is obvious hollow rivets should be used. With equal cross-section area the moment of resistance of hollow rivets is greater, and the latter therefore give a theoretically higher strength.

In practice, however, the actual hollow rivets are not suitable for the transmission of high stresses, for the following reasons:—

Generally the hollow rivet is a sleeve or tube, the closing head of which is formed by flanging or widening its free end mainly by pressing in an axial direction of a rotating or axially slidable tool.

The hollow rivet undergoing radially a slight pressure only, the rivet hole is not entirely filled out, while on the other hand there is no sheet clamping at all during the driving process and the rivet shaft is not so much driven in an axial direction, that the sheets between rivet head and closing head are pressed sufficiently together.

These are the causes of the diminution of the crushing strength. Further, the rivet heads, and more particularly the closing heads, are of small sizes, so that the rivets are easily pulled through the metal sheets if under axial stress. For this reason the actual hollow rivet types are not so much rivet-like as bolt-like connecting elements. Their field of application is restricted further by the fact that they do not allow a smooth surface in the skin and that they partly allow moisture to pass into the interior of the structures.

For all these reasons the use of hollow rivets is restricted to structures not too highly stressed, provided that, owing to their particular structure, accessibility is given from one side only. In Germany, hollow rivets are therefore used only for riveting of joints with tubes not accessible from the inside at all, or to some extent only; for the ultimate fixation of the closing caps to the wing tips or control surfaces; and last, though not least, for riveting of provisional repairs in case of damages.

As the hollow rivet methods known in Germany do not differ much from those used in England I can refrain from a detailed description of these methods and therefore beg to refer to German literature concerning this matter.*

Complying with the request of Major Wylie and Mr. W. C. Devereux, I give the following complementary details on the Heinkel-Sprengnietverfahren (explosive rivet method) which has recently been mentioned in English publications. I did not mention this special method in my lecture because it was my intention to refer to riveting methods actually used and approved in practice. Seeing, however, a general interest in this new German method, I am glad to be able to give further details of it.

* See W. Pleines. Riveting in Light Metal Construction. Zeitschrift Werkstattstechnik und Werksleiter, XXXI, Vol. 1937, No. 17/18.

THE HEINKEL- EXPLOSIVE RIVETING.

The problem of riveting structural parts accessible from one side only has not yet been completely solved. Investigations have led to the development of the Heinkel- He N- explosive riveting method, the advantages of which are the following:—

(1) Absolute independence of accessibility to the riveting place at the closing head side; in other words, perfect riveting of absolutely closed profile is ensured.
(2) Full utilisation of the rivet material and its physical material-characteristics.
(3) Minimum space practically required at rivet head and closing head side.
(4) The full solid shaft cross-section area is maintained; consequently the shear strength of the rivet is about 80 to 90 per cent. of the figures obtainable for standard solid rivets.
(5) Direct water-tight riveting is rendered possible.
(6) This method can be applied for all materials of structural parts and rivets, the ultimate elongation of which is more than 15 per cent.
(7) Short working-times.

The application of this riveting method, however, requires specially-prepared rivets (explosive rivets, which now can be obtained in the trade) and special technological working-processes.

FIG. 1.
Explosive rivet before (a) and after (b) explosion.

(*a*) *The Explosive Rivet.*

The explosive or He N-rivet differs from the standard solid rivet by a bore provided at the free shaft-end (hollow shaft-end), filled with a firmly pressed-in organic explosive of a special composition, protected outside against weather influences by a coat of varnish. This explosive is non-corrosive, either in burned or in unburned condition. The outer dimensions, and more particularly the rivet head shapes, are as those of standard solid rivets for light-metal construction. The rivets are made simultaneously with their bores according to a special drawing-process in order to ensure uniform rivet shapes and material characteristics. The lengths of rivets for given sheet thicknesses (clamping-lengths) are so graduated that the part of the rivet shaft which transmits the shearing-stress (clamping-length) remains practically unlessened. The explosive charge is ignited by a special method, described under (*b*); the explosion causes a plastic deformation of the free rivet shaft end to the barrel shape swelling shown in Fig. 1. The swelling of the explosive closing heads should be 25 per cent. with light-metal rivets, and 15 per cent. of the shaft diameter with steel rivets. It extends as far as the bottom border of the sheets; owing to the " key " effect, tight fit of the rivet shaft, inserted without clearance, and some clamping of the sheets are obtained. Bulging structural parts must be clamped beforehand, because no checking with a view to correct closing head formation is possible afterwards. Explosive rivets are actually supplied in diameters of from 2.6 to 6.0 mm. To prevent the heat from spreading throughout the part being riveted, the rivets are covered with a coating of Eloxal, which has insulating properties.

(*b*) *Riveting Method.*

Drilling is done as usual; care should, however, be taken that drilling is done absolutely at a right angle. It is advisable to drill within a range of 2.6 to 6.0 mm. hole diameters with undersize of 0.5 to 1.0 mm. first, and then ream the holes to their exact diameter (which is equal to the rivet diameter) and remove the burr. The rivet is then pushed in by a slight blow, in order to ensure safe setting-on of the rivet head bottom to the metal sheet. The explosive charge is

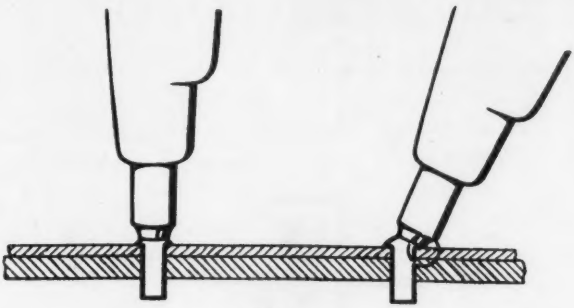


FIG. 2.

Correct and incorrect setting-up of the heating tool.

This set must always be kept bright!

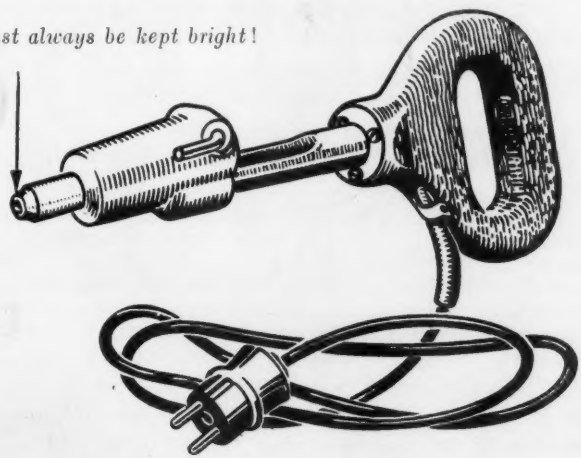


FIG. 3.

Electrically-heated tool, used for explosive riveting.

fired by holding a hot special holding-up tool against the rivet head until the explosive rivet has been heated to about 120° to 130°C. For this operation it is essential that setting-up of the holding-up tool is done at right angles to the part being riveted. The metal sheet should not be touched by the tool (see Fig. 2).

The explosive was chosen with a view to following requirements:—

(1) Low ignition temperature, in order to avoid detrimental heat influence on the physical properties of the light metal to be riveted.

(2) Unlimited possibility of storing, even in the tropics.
(3) Maximum safety of handling in production and maximum freedom from friction and shock.
(4) The explosive and its gases must be non-poisonous.

The holding-up tool, which is electrically heated, may have a silver or an aluminium head (copper is unsuitable) which is shaped to fit whatever sort of head the rivet has (see Fig. 3).

Some modified shapes of the tool set (ignition piston) are necessary where accessibility is restricted owing to special design of structural parts (see Fig. 3A).

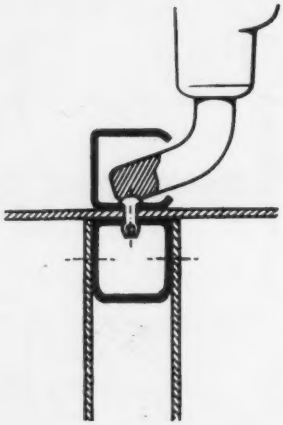


FIG. 3a.
Explosive riveting at parts with minor accessibility.

The ignition piston must have a metallic bright surface in order to ensure quick heat-transmission. The heating time to cause explosion is about 2 seconds. It will be the shorter the higher the temperature of the heating tool is (about 300°C. to 400°C.), and the risk of the material round about the rivet getting too hot is lessened with increasing heat of the tool. The detonations are rather slight. Oxidation and uncleanness involve longer heating-times and are the cause of failures in explosion.

(c) *Convenient Ratio of Rivet Length and Sheet Thickness (Grip).*

For the selection of the convenient rivet size the same principles should be heeded which are valid for solid rivets, save for the values of shear strength, which are somewhat lower. The total rivet shaft length L_1 (see Fig. 4) is computed as follows: $L_1 = L_2 + s$

where s = total sheet thickness (grip) and
L_2 = free shaft length = $(L_1 - s)$.

The sheet thickness or grip should be measured immediately on the part to be riveted and not be noted from the drawing.

Care should be taken that the single sheets be well clamped.

The specifications of the explosive rivet are given in Fig. 4, a figured example for a special rivet shape in Table I. In order to classify the rivet shaft lengths more easily and to render easier checking of a completely riveted joint with regard to correct shaft length, the rivets are given different colours.

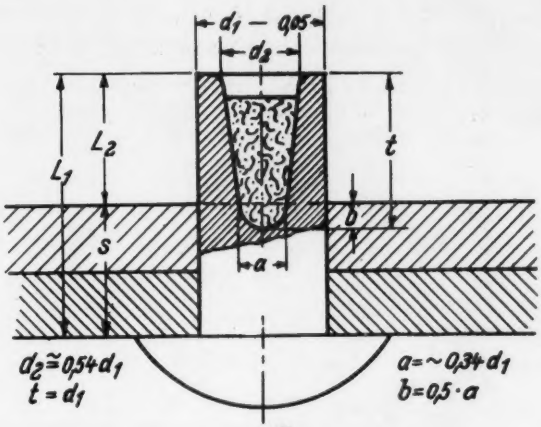
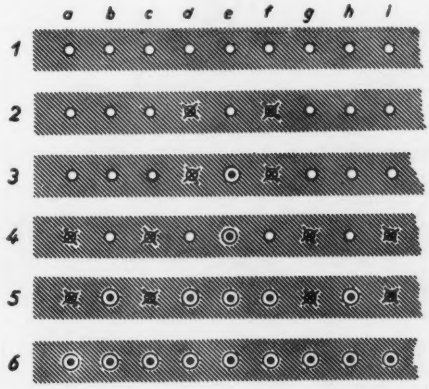


FIG. 4.

Specifications of the He N explosive rivet.



○ *Drilled hole.*

⊠ *Clamped with special screws.*

◉ *Riveted.*

FIG. 5.

Explosive riveting of long rivet seams.

Order of operations (rule):—

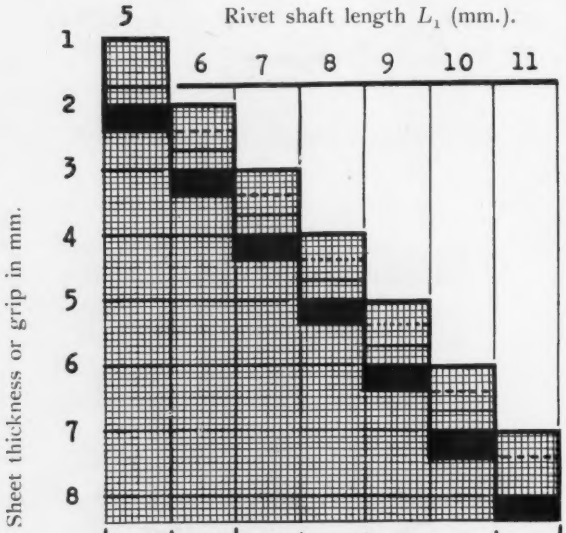
1. *Drill holes.*
2. *Clamp holes (d) and (f).*
3. *Rivet hole (e).*
4. *Clamp holes (a), (c), (g) and (i).*
5. *Rivet holes (b), (d), (f) and (h).*
6. *Remove clamp screws at (a), (c), (g) and (i) and rivet the remaining holes.*

TABLE I.

VALUES OF DIMENSIONS FOR EXPLOSIVE RIVETS WITH FLAT ROUND CLOSING HEADS.

d_1	mm.	2.6	3.0	5.0
d_2	mm.	1.4	1.6	2.7
L_1	mm.	3.0	4.0	7.0
s	mm.	0.85	1.5	2.85
L_2	mm.	2.15	2.5	4.15
t	mm.	2.6	3.0	5.0
a	mm.	0.9	1.0	1.7
b	mm.	0.45	0.5	0.85

TABLE II.



S_{min}	1,0	2,0	3,0	4,0	5,0	6,0	7,0
S	1,7	2,7	3,7	4,7	5,7	6,7	7,7
S_{max}	2,4	3,4	4,4	5,4	6,4	7,4	8,4

Explosive flat round head rivet $4 \times L_1$ *He N*.

For the selection of the most suitable rivet lengths for determined sheet thicknesses the rule should be noted that to obtain the best clamping effect the value for $(L_1 - s) = L_2$ should always be *smaller* than the above L_2 values. The clamping lengths or grips s, admissible in every instance, can be noted from tables drawn up in accordance with practical experience. An example of this is given in Table II.

Rule: The shorter rivet is to be chosen, if *one* sheet gauge can be clamped with rivets of different lengths (see " filled-up " field limit in Table II).

(*d*) *Special Rules for the Practice of Riveting with Explosive Rivets.*

(1) *For riveting of long rivet seams*:

Previous to riveting, all structural parts must, as a general rule, be clamped tightly by means of special clamping screws suitable for clamping of parts with accessibility from one side only. In addition, for drilling, clamping and riveting long rivet seams, the following rule for the order of operations should be noted (see Fig. 5).

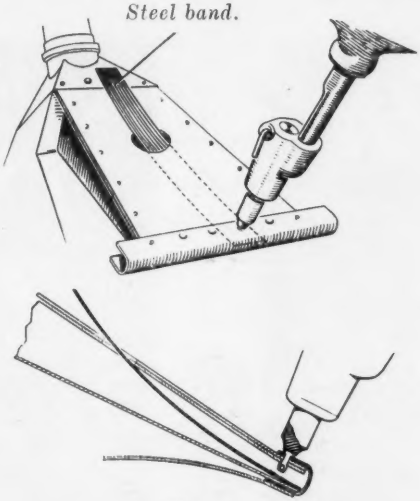


FIG. 6.

Arrangement preventing effect of explosion on parts opposite to explosive rivet (closing head).

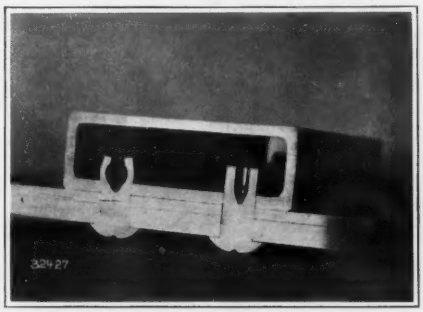


FIG. 6*a*.

Section through an Heinkel explosive rivet before and after explosion, accessible from outside only.

(2) *For riveting of structural parts, the walls of which are near the opposite closing heads of explosive rivets.*

If opposite to the riveting place at the closing head side there are structural parts at a distance of less than 6 mm., the surface exposed to damage by the explosion should be protected by a piece of springy metal (see Fig. 6).

Explosive riveting offers new possibilities of application (see Figs. 6*a*-6*d*). Extended load tests made by Heinkel-Flugzeugwerke on structural parts (wing spar) riveted in this manner have shown that under bending load according to case " A " all riveting joints were intact even at 85 per cent. of breaking load.

Replying to Mr. Devereux's further remarks, I would add that the alloys duralumin 681 A and 681 ZB 1/3 are preferred in Germany as rivet materials; both belong to the alloy class Al-Cu-Mg.

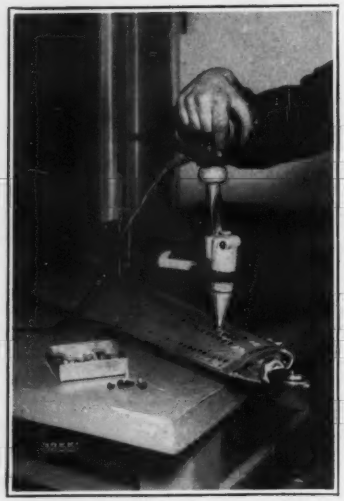


FIG. 6*b*.

Electrically heated firing tool, correct use.

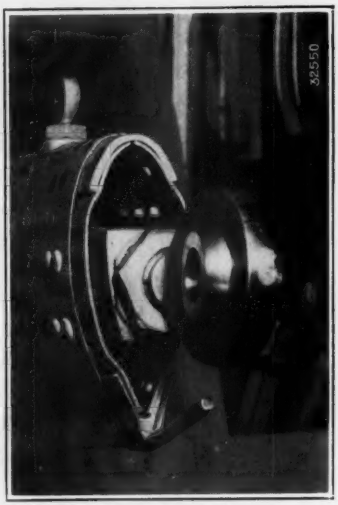


FIG. 6*c*.

Fitting of a strut riveted with Heinkel explosive rivets (see also Fig. 6b).

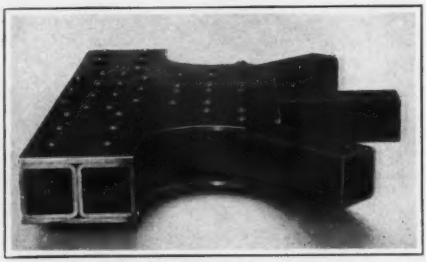


FIG. 6*d*.

Structural part, accessible from outside only, riveted with Heinkel explosive rivets.

With the principally-used rivets of alloy duralumin 681 ZB 1/3 the shear strength τ_s of the fully-aged rivet wire or rivet is about 27 kg/mm² *previous to being driven*. For the *driven* rivet, however, the shear strength is only about 25 kg/mm² after ageing (five days). Rivets of the alloy 681 A, which have good forming-characteristics, especially used for mushroom head rivets, have a τ_s of

about 25 kg/mm² previous to driving, and of about 23 kg/mm² after having been driven. A reason put forward for this decrease of shear strength after driving is that owing to the driving process the ageing effects are altered and that consequently it is impossible to obtain the increase of the physical characteristics to the same extent as by undisturbed ageing.

With regard to Mr. Devereux's further question about the annealing temperatures of 500°C., which are much higher than is admitted by English rules, I suggest the following explanation:—

For rivet materials of the dural type (Al-Cu-Mg class) there exists in Germany instructions that, according to the percentage of copper, the material is to be heated to about 500° to 505°C. in order to obtain a good solution of the hardening ingredient with the Al-crystal.

The chemical composition of these alloys according to the general rules is given in the following limits:—

3·7 to 4·7 per cent. Cu.
0.4 to 1 per cent. Mg.
0.1 to 0.7 per cent. Si.
0.3 to 0.7 per cent. Mn.
$<$ 0.5 per cent. (Fe + Ti).
$<$ 0.1 per cent. Zn.
Rest: Aluminium.

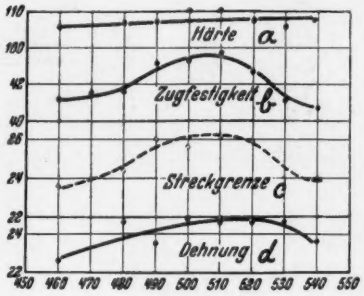


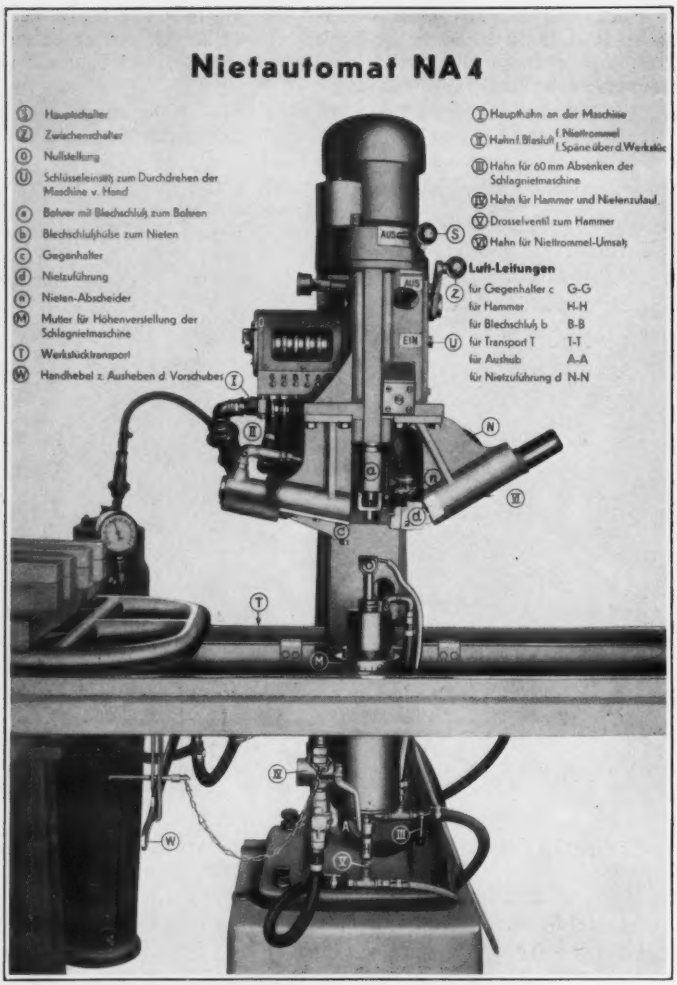
FIG. 7.

Influence of anncaling temperature on strength characteristics for avional duralumin (v. Zeerleder).
Annealing temperature (in degrees C.).

(*a*) *Hardness.*
(*b*) *Tensile strength.*
(*c*) *Yield point strength.*
(*d*) *Elongation.*

The dependence of physical qualities (tensile strength, yield point strength, elongation, hardness) on the annealing temperature as set forth by Fig. 7 shows a remarkable maximum at the above temperatures; though it must be admitted that heating must be made within very narrow limits of temperature in order to obtain equally high mechanical values at all points of the part.

To Mr. Devereux's and also to Dr. Sutton's question if retarded ageing dural-alloys are likely to displace actual rivet materials (for more details about this problem see: K. Matthaes, Langsam aüshärtende Leichtmetalle . . . , Zeitschrift für Metallkunde, 30 Fahrg, No. 7 (Juli, 1938), S. 238 ff.), I would say that in my personal opinion this will be the case. Even a loss of 10 to 15 per cent. of the maximum values of the physical properties, which are usual with actual rivet materials, will be allowable if we obtain in their stead better forming-characteristics and consequently an accelerated production. It is a fact that the rivet joints of light-metal construction, and particularly in light-metal aircraft construction, are



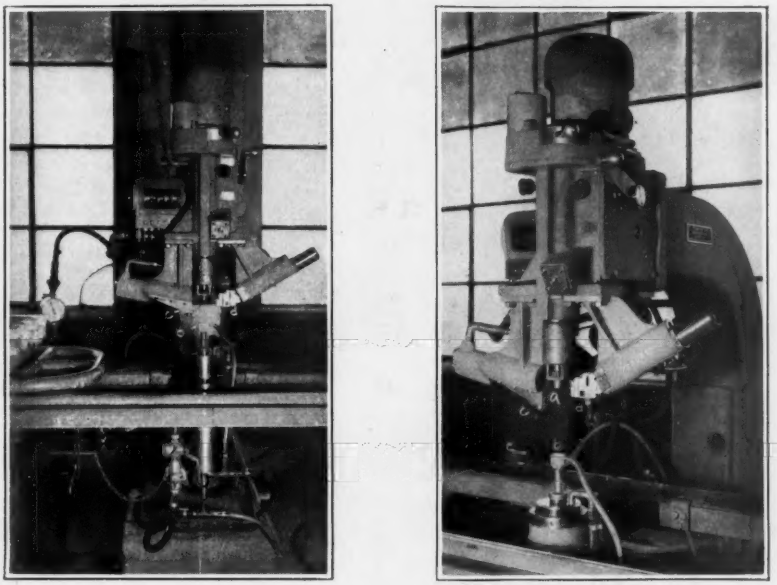
S.—Main switch.
Z.—Intermediate switch.
O.—Zero position.
U.—Peg for turning the machine by hand.
a.—Drill with sheet clamping device for drilling.
b.—Sheet clamping sleeve for riveting.
c.—Dolly.
d.—Rivet feed.
n.—Device for separating the single rivets.
M.—Rivet for height adjustments of the percussion device.
T.—Forward feed of work.
W.—Hand-lever disengaging forward feed.
I.—Main cock on the machine.
II.—Cock for blown air { for rivet drum. / for chips above the work.
III.—Cock for lowering the percussion device by 60 mm.
IV.—Cock for hammer and rivet supply.
V.—Throttling valve for hammers.
VI.—Cock for rivet-drum advance.

Air pipes:
for dolly (*c*) G—G; for hammer H—H; for sheet clamping (*b*) B—B; for forward feed T—T; for disengaging A—A; for rivet supply (*d*) N—N.

FIG. 8*a*.

General view of the FMA automatic repetition riveting machine, type NA 4.

a priori considerably oversized. It is a mistake to take as a basis for strength calculation of multi-rivet joints those values which are derived from static tests made on single-rivet joints, because the partial load on the single-rivet in multi-rivet joints, especially under alternating endurance load, is of quite another nature, which has not yet been sufficiently investigated. Also shortcomings in technological manufacture, which are frequently the cause of great variations in test results, can doubtlessly be lessened where the rivet material has better plastic and forming properties.



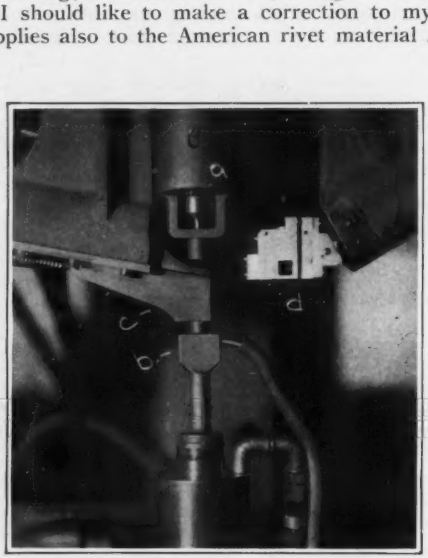
FIGS. 8*b* AND *c*.

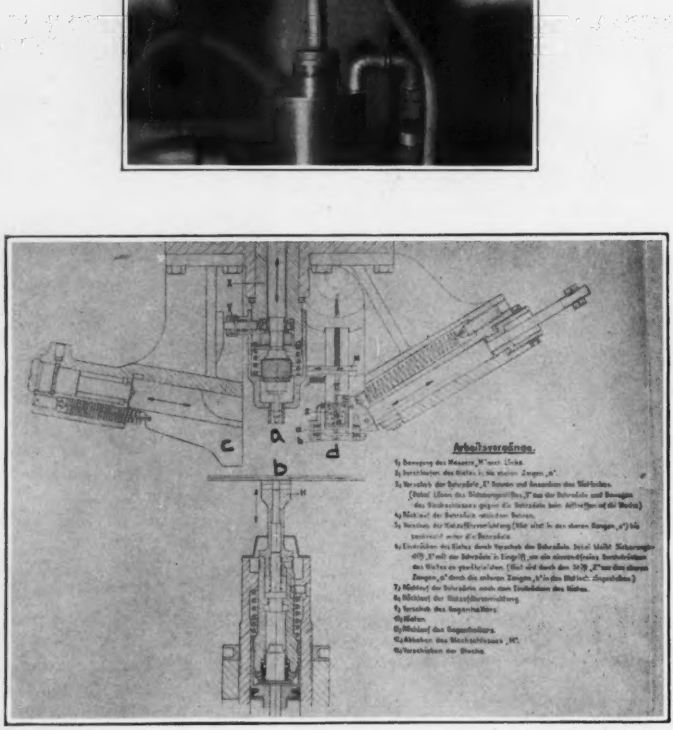
General view of the FMA automatic repetition riveting machine, type NA 4.

(*a*) *Drilling and countersunk devices with sheet clamping device, movable in upward and downward direction.*
(*b*) *Heading tool (blowing hammer) with sheet clamping device, movable in upward and downward direction.*
(*c*) *Dolly (holding-up tool) movable in upward and downward direction on an oblique slide.*
(*d*) *Rivet feed and insertion device, with rivet guide tongs, movable in upward and downward direction on an oblique slide.*
(*e*) *Advancing arrangement.*

Another rivet material has been developed recently in Germany, namely, the alloy duralumin 681 H, the shear strength of which in comparison with present rivet materials of the dural-type (duralumin 681 A and ZB 1/3) is lower, namely, instead of $\tau_s = 25$ to 27 kg/mm², its *minimum* shear strength is $\tau_s = 22$ kg/mm², but it is, however, of good ductility in fully-aged state. It is therefore useful, especially for cold driving of rivets; and a particular advantage over the above-mentioned alloys is to be found in the fact that duralumin 681 H need *not* be

heat-treated before driving, but can be used in its aged state as long as desired. In this connection I should like to make a correction to my former statements inasmuch as this applies also to the American rivet material A 17 ST, mentioned in my lecture.





FIGS. 8*d* AND *e*.

Partial view and sectional drawing of the working of the FMA automatic riveting machine, type NA 4.

(*a*) *Drilling and countersunk devices with sheet clamping sleeve.*
(*b*) *Heading tool (blowing hammer) with sheet clamping sleeve.*
(*c*) *Dolly (holding-up tool).*
(*d*) *Rivet feed and insertion device.*

The question raised by *Mr. Radcliffe* and the fact connected with it, that I have refrained from giving in my lecture a description of the FMA automatic riveting machine, on account of the film shown, makes me give the following description :—

The operations which must be made in succession in order to obtain a riveted joint, namely, *drilling, countersinking (with cutting detachment)* or—for riveting by driving-in (dimpled joint)—"*dimpling*" *of sheets, insertion of rivets, driving and heading of rivets* are made fully automatic in one vertical axis, the sheets being clamped, without a displacement of the work during the operations (see Fig. 8*a* to *e*).

The drill (*a*) with the upper sheet clamping-sleeve is arranged above, and the riveting hammer (*b*) (multi-blow hammer principle for instance), likewise with sheet clamping-sleeve, below the work, drill and hammer axis being aligned in one common vertical symmetrical axis. The dolly (*c*) and the rivet insertion device (*d*) are likewise arranged above, in lateral position. Both parts perform, besides a translatory reciprocating movement in the direction of the rivet seam, an up-and-down movement.

By the provision of a supplementary working-table with slide and an automatic advancing arrangement (*e*) (see Fig. 8A) a solid fixing of the work during the riveting operation and the subsequent transportation of it, in accordance with even rivet spacing provided, is ensured within wide limits (up to 250 mm. = 10 ins.). Where this equipment is not provided, the work may as well be moved by hand. All these operations being performed in one vertical axis, it is also possible to rivet curved structural parts. Fig. 8D shows details of the arrangements described (*a-d*). Fig. 8E shows besides a drawing of the fundamental arrangement and the design of the automatic riveting machine.

Save for the electrical drive of the drilling tool, all operations are governed by *compressed air*. The order of operations of the machine is the same as for making a riveted joint, and as shown in Figs. 9A-C, namely :—

First operation (Fig. 9A): *Drilling*:

Drilling, and also simultaneous countersinking (with detachment of cutting) is made from above. The tool (*a*) consists of a drill, combined with a countersink. The drilling spindle is automatically movable upward and downward. *During this operation the sheets are tightly clamped.*

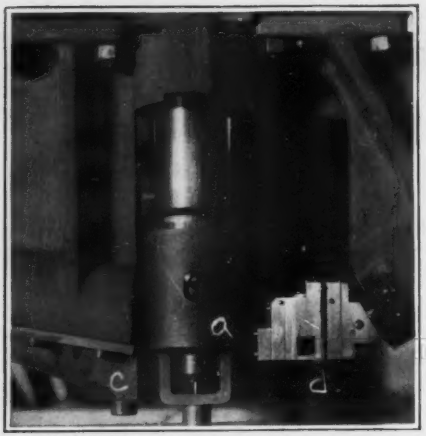
Second operation (Fig. 9*b*): *Rivet feed and insertion*:

The rivet is by positive movement inserted in the rivet hole, with its shank end downward. The rivet feed (*d*) is arranged above, laterally. During the drilling operation it remains in its position of rest. It moves in a downward direction on an oblique slide when the drilling spindle is in its top end position. After the finish of its downward movement the rivet is positively held in a pair of rivet guide-tongs in a vertical position above the rivet hole. The rivet feed is so arranged that at the following new downward course of the drill holder—without the drill coming into engagement—the rivet is pushed from the rivet guide-tongs into the rivet hole below. After this, the rivet feed is, by means of a spring, pulled back again into its lateral position of rest.

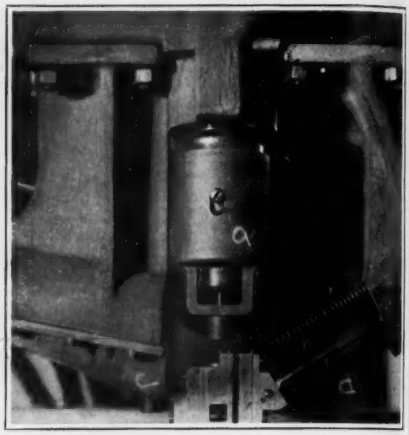
Third operation (Fig. 9C): *Rivet driving and heading.*

The rivet is driven and headed. To perform this, a dolly (*c*), placed laterally above, also on an oblique slide, slips in and is advanced to a point above the die-head, whilst a riveting hammer (*b*) arranged beneath the sheets, and movable upward and downward, lifts and strikes against the free rivet shank until the rivet is sufficiently driven and the free shank end formed to a flat head. The riveting hammer is also surrounded by a *sheet clamping sleeve*, movable upward and downward, which provides for absolute tightness between the sheets. Both parts move downward together when the rivet is finished and give free passage for the subsequent movement of the work.

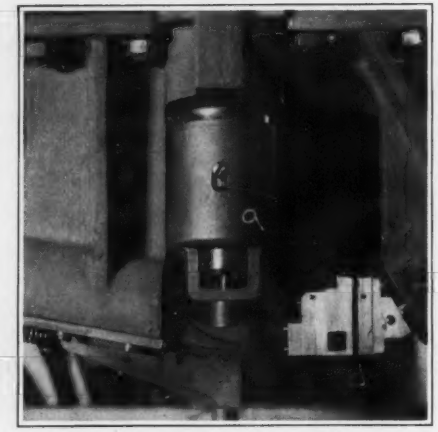
The operation No. 3 has recently been modified to perform in addition the operations required for flush riveting by special countersinking and driving-in, namely, " pulling through " of the material around the holes, without detachment of cutting, whilst the rivet is being driven in.



9*a*.



9*b*.



9*c*.

FIGS. 9*a*, *b* AND *c*.

Position of the above working devices.

Drill (*a*),
Dolly (*c*),
Rivet insertion device (*d*),
for the following operations:—

9*a*: *Drilling and countersinking, the sheets being clamped.*
9*b*: *Rivet feed, an insertion* (*a*) *being in its downward course.*
9*c*: *Dolly at rivet heading. the sheets being clamped.*

It is important that during the *driving and heading operation the sheets be clamped* in the same manner as for drilling—that is to say, that the sheets be pressed together by the clamping device, which can be raised from below, and the dolly, which is pushed down from above.

The FMA automatic riveting machine has the following special features:—

Feeding of rivets is made from a magazine formed by a rotating drum, into which rivets of equal sizes and of a determined shape are thrown any way. The bottom of this drum is of a special design, causing the rivets to come into line, which continually moves from the drum down to an oblique slide, whence the rivets pass one by one—with their free shank end directed downward—through

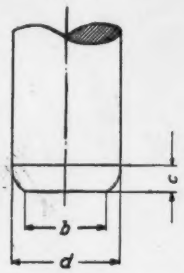
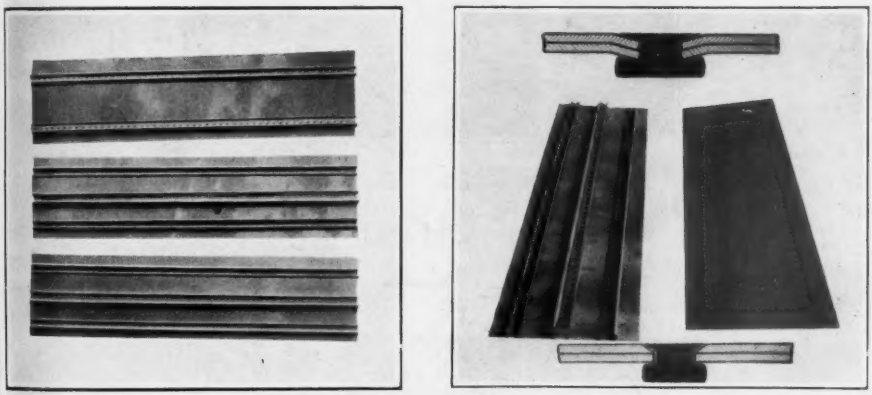


FIG. 9*d*.



FIGS. 10 AND 11.

Structural parts of "stressed skin" construction in aeroplane design, flush riveted with the FMA automatic riveting machine.

a separating device to the rivet insertion device (rivet guide-tongs). The rivet feed and the insertion mechanism can, of course, work safely only with perfect rivets. According to this question I must refer to the fact that in U.S.A. certain sizes of Al. alloy rivets can now be supplied with the shank ends chamfered (see Fig. 9*d*) thus simplifying insertion of the rivet into the hole, particularly with automatic riveting machines.

A regular feed and supply of only one rivet at a time to the tongs is guaranteed by this supplementary arrangement. It must be changed, however, when rivets of other shapes and sizes are to be handled.

If the rivet shaft dimensions are equal, flat-round, half-round and countersunk head rivets can be fed with the same rivet feeder; if the rivet shaft dimensions are different, one rivet feeder and the same rivet guide-tongs are necessary for rivet diameters of 2.5 to 3.0 mm. and a different set for rivets of 3.5 to 4.0 mm. The change of these parts can be done in less than five minutes.

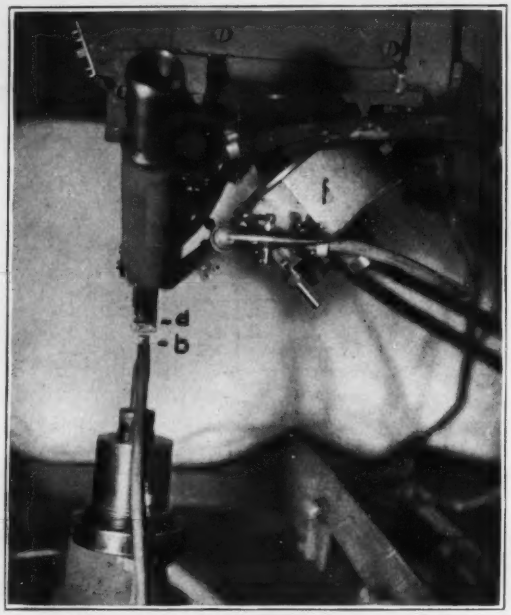


FIG. 12.
Side view of the heading tool with sheet clamping device (b), rivet guide tongs (d), and rivet drum (f).

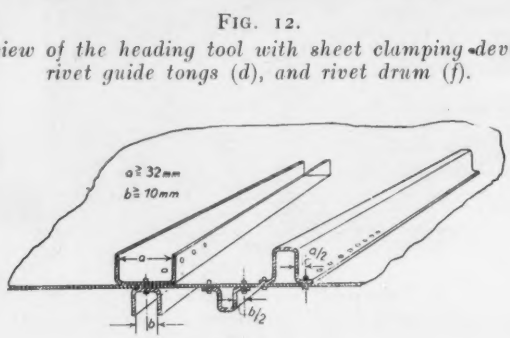
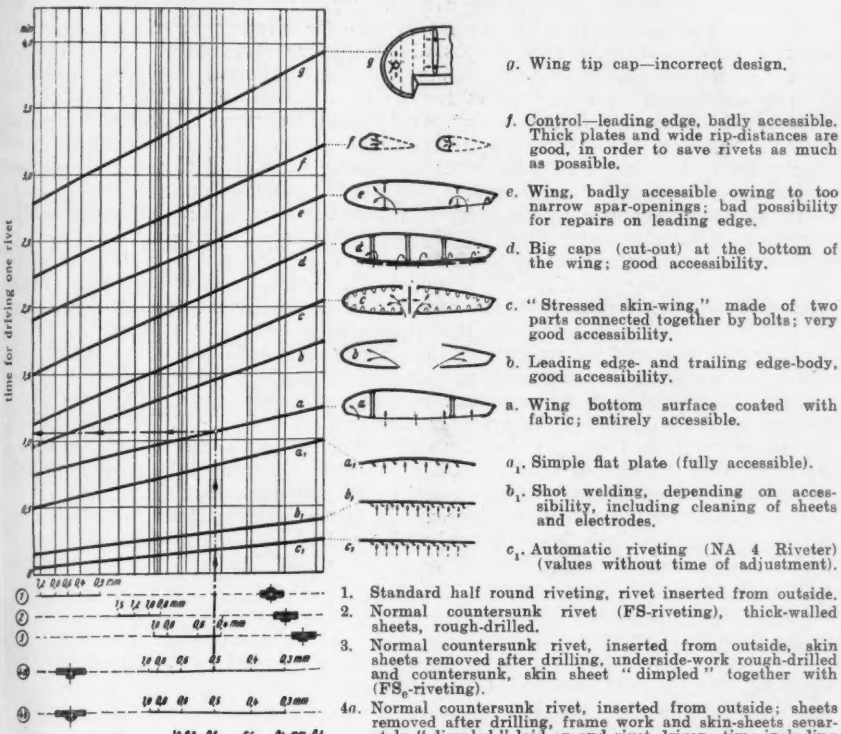


FIG. 12a.
Minimum width of flange or distance of rim respectively for top or bottom profiles, depending on the width of the rivet guide tongs (top) or of the dolly with sheet clamping device (bottom) respectively.

All chips generated at drilling and countersinking are removed immediately by compressed air.

For the application of the automatic riveting machine described above, it is necessary that the upper side of the structural parts to be riveted is flat, at least

to a width equal to that of the rivet guide-tongs. This riveting machine is therefore especially suitable for riveting thin sheets with longitudinal and transversal stringers of an open or partially open profile on the interior side (in the present case at the bottom), as for instance structural parts designed in " stressed skin " construction (see Figs. 10 and 11). The width of the studs of these profiles at the bottom part is limited only so far as the rivet set and the sheet clamps must



g. Wing tip cap—incorrect design.

f. Control—leading edge, badly accessible. Thick plates and wide rip-distances are good, in order to save rivets as much as possible.

e. Wing, badly accessible owing to too narrow spar-openings; bad possibility for repairs on leading edge.

d. Big caps (cut-out) at the bottom of the wing; good accessibility.

c. " Stressed skin-wing," made of two parts connected together by bolts; very good accessibility.

b. Leading edge- and trailing edge-body, good accessibility.

a. Wing bottom surface coated with fabric; entirely accessible.

a_1. Simple flat plate (fully accessible).

b_1. Shot welding, depending on accessibility, including cleaning of sheets and electrodes.

c_1. Automatic riveting (NA 4 Riveter) (values without time of adjustment).

1. Standard half round riveting, rivet inserted from outside.
2. Normal countersunk rivet (FS-riveting), thick-walled sheets, rough-drilled.
3. Normal countersunk rivet, inserted from outside, skin sheets removed after drilling, underside-work rough-drilled and countersunk, skin sheet " dimpled " together with (FS_e-riveting).

4*a*. Normal countersunk rivet, inserted from outside; sheets removed after drilling, frame work and skin-sheets separately " dimpled," laid on and rivet driven; time including removal and " dimpling " (most perfect smoothness of surface obtainable—FS_m-riveting!)

4*b*. Mushroom-rivet inserted from inside, holder-on from outside, sheets " dimpled " simultaneously with setting up of rivet, driving from inside (P-riveting).

5. Normal countersunk rivet, inserted from outside, sheets " dimpled " simultaneously with setting up of rivet, holder-on from inside, and then driven.

FIG. 13.—Riveting-times necessary for driving one rivet into a wing, according to accessibility of wing and special shape of rivet and rivet joint as parameters.

a to *g*: Wing designs with different degrees of accessibility. a_1 to c_1: Test samples of equal design. The rivet work according to a_1 and *a* to *g* requires *two* men, according to b_1 and c_1 *one* man only. Rivet diameter from 2.5 to 4 mm.

Example (dot-and-dash line) given for riveting method (4*a*) and 0.5 mm. sheet thickness for wing-design (*a*).

be arranged for free movement. These, however, are so narrow that all profiles met with in practice can easily be riveted (see Fig. 12, being a side view of the machine, and Fig. 12*a* a sketch of minimum part dimensions). Thanks to a rigorous restriction of the dimensions of the rivet tongs, the dolly and the riveting hammer (snap) with sheet clamps, the requirement of plain and even surfaces is considerably lessened. This refers in almost the same degree to the

top of such parts, so that bars or other parts with double-sided profile-shaped longitudinal beams may be riveted (see Fig. 12*a*).

In order to show the advantages for rapid working resulting from the use of such riveting machines, I refer to the following Fig. 13, taken from a report given by Mr. O. Oeckl, Henschel-Flugzeugbau, " Construction and production actually in use in light-metal aircraft " (VDI-Zeitschrift, Vol. 82, No. 11, of 12th March, 1938).

This diagram shows the riveting times required for one rivet driven into a wing with different degrees of accessibility to the riveting place according to different designs, the different shapes of rivet joints and different sheet thicknesses (clamping-lengths or grips) being taken into account. By *riveting time* is to be understood the time required for one rivet joint, after all holes have been drilled. There are also included all working times for removal of clamping screws and, for instance, with riveting method (4*a*) (see Fig. 13), for removal of skin sheets, for " dimpling " of skin sheets and frame work, and for refixing of the skin sheets. It will be noted from this diagram the influence on the riveting time of the degree of accessibility, in every instance; the riveting time is considerably increased with minor accessibility. On the other hand, the great advantages presented by automatic riveting machines when used for riveting of designs with good double-side accessibility will be noted. It should be mentioned that these studies of riveting times are based on tests made when this apparatus was in its first state of development; and that the apparatus has in the meantime been considerably improved. Another very important factor in favour of the automatic riveting machine is that one man only is required, whilst for all other riveting methods mentioned, two men are necessary to make rivet joints. This fact contributes to the solution of the problem how to save labour. It will also be of interest to note from Fig. 13 that the time required for riveting, when an automatic riveting machine is used, is still considerably less than the time required to make a shot-welding-point under equal conditions of accessibility.

The reason why riveting times increase in inverse rate to sheet thicknesses is mainly that thin-walled sheets must be clamped at smaller spaces than thick-walled sheets and that they demand more care while riveting. I think that in view of these results gained from practice it will be superfluous to give further reasons to show the advantages of machine riveting.

The following remarks in reply to Dr. Sutton's further questions:—

For the special magnesium alloys MG 5 and MG 7 used as rivet materials in Germany, the following strength figures can be assumed:—

Magnesium alloy, used as rivet material	Shear strength τ_S, kg./mm.²	Tensile strength σ_B, kg./mm.²	Ultimate elongation δ, %
MG. 5	~20.0	23 to 25	16 to 22
MG. 7	~22 to 23	31 to 35	16 to 22

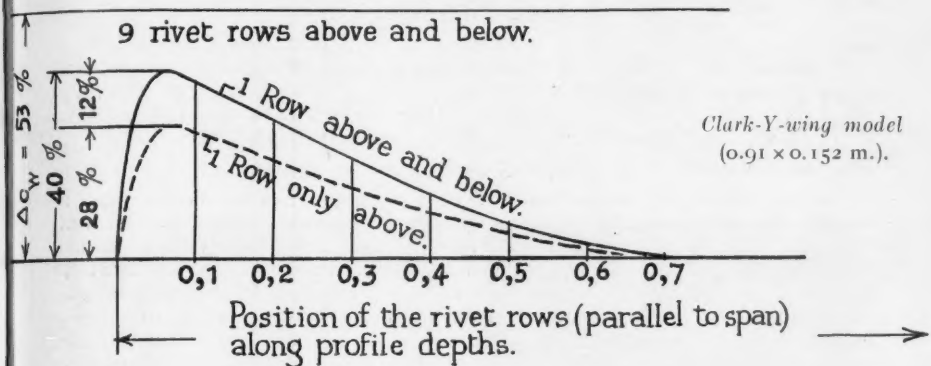
The admissible crushing strength in AZM sheet and press material is 40 to 50 kg/mm², in AM 503 sheet and press material, as well as in all casting alloys, 30 to 40 kg/mm². For riveting of minor-stressed parts, rivets of pure aluminium can be used instead of these alloys, but not iron, copper or duralumin rivets.

With regard to the question whether in using the single-blow principle high additional tensions in the rivet shaft must be considered, I would say that from present experience there is no reason to presume this. On the contrary, the single-blow principle has recently been used to a steadily increasing extent for driving the stronger light-metal rivets.

To *Mr. Davies'* question I can reply only that in Germany appropriate methods of shot-welding for light metals have been developed. I have not studied this sufficiently, however, to comment.

The Chairman, *Mr. A. Hall*, sees one way to decrease the relatively high working times for riveting in that the designer should be asked to lessen the

number of rivets. In my opinion this would be rather difficult for the designer, for the development of " stressed skin " structures requires, on the contrary, more and more rivets in the skin to be used. Referring to Fig. 13, I reiterate that it will be more economical to design parts to be riveted so as to make it easy to carry out automatic riveting, as by this means a considerable amount of working time and of men employed can be saved.



Clark-Y-wing model (0.91 × 0.152 m.).

Δc_w = additional friction drag owing to rivet rows in percentage of minimum profile drag coefficients $c_w = 0.0015$.

$W_{ges} = F\,(\gamma/2\,g)\,v^2\,(c_w + \Delta c_w)$. Reynolds number $R = \sim 0.25 \cdot 10^6$.

FIG. 14.

Influence of rivet row (flat round rivet heads) on the minimum profile drag of a wing.
(N.A.C.A. wind tunnel tests.)

With reference to the further question on the influence of rivet heads in the skin on the profile drag of a wing, I refer to Fig. 14, setting out the results of N.A.C.A. wind tunnel tests (N.A.C.A. T.N. 461) concerning the influence of half-round rivet heads on the minimum profile drag of a wing section. According to more recent investigations at higher Reynolds number (see A.R.C., R. & M. 1789) the increase of the minimum profile drag is not quite as high, namely, only about 8 to 10 per cent.; but even this amount is rather considerable in view of the fact that with modern high-speed aeroplanes the portion of the profile drag is as much as 40 per cent. to 50 per cent. of the total resistance. Another reason why flush riveting should be used for the wing is that even slight elevations of rivet heads increase considerably the possibility of ice formation.

I fully agree with Mr. Hall that the need for flush riveting would be invidious if, for instance, a streamline shape of the fuselage is afterwards ruined by protuberances required for military reasons. In this case there is no just reason for flush riveting along the whole fuselage. In Germany, such fuselages are flush riveted only in the forward section of one-third the total length, and the rear seams have half-round or flat-round rivet heads.

The 632nd Lecture read before the Royal Aeronautical Society since its foundation on January 12th, 1866.

PROCEEDINGS.

A Meeting of The Royal Aeronautical Society was held in the Lecture Hall of the Institution of Mechanical Engineers, Storey's Gate, S.W.1, on Thursday, 7th April, 1938, at 6.30 p.m., when a Lecture by Dr. E. G. Richardson, B.A., Ph.D., D.Sc. on " The Manipulation of the Boundary Layer " was read.

In the chair: Mr. E. F. Relf, F.R.Ae.S., *Member of Council.*

THE CHAIRMAN: Dr. Richardson had been engaged for a number of years in research work in acoustics and aerodynamics. At one time he worked with Dr. Piercy, and since then with Dr. Tyler at University College, London, and King's College, Newcastle. In 1927 he distinguished himself in the annals of the Society by winning the Busk Prize for a paper on " Recent Experiments in Fluid Motion." Dr. Richardson was one of those fortunate people who, living in a University atmosphere, were free to do what research they liked, within certain limits. The paper showed that he had been conducting some interesting experiments in various aspects of the boundary layer, ascertaining what could be done by modifying the flow and so forth. It was a very important subject, because a better knowledge of the boundary layer and how to obtain more power over it might open up a great future for research in aerodynamics.

THE MANIPULATION OF THE BOUNDARY LAYER.

By E. G. RICHARDSON, B.A., Ph.D., D.Sc.

In this paper I have endeavoured to give an account of the various methods which have been employed in the past ten years to alter—for better or worse—the conditions in the boundary layer of a body in turbulent flow. I have refrained from speaking of " control " in reference to the boundary layer, since in the minds of most people, this implies an amelioration of the flow and a reduction of drag. As will appear in what follows, some of the devices in which I and other experimenters have been concerned have just the opposite effect. Nevertheless, following the principles current in clinical research in medicine, I think we should find both what conditions will cause " deterioration "—if one may use the term—as well as those which will cause " improvement " of the flow round a body, if we are to progress in our knowledge of the state of affairs in the boundary layer. Working rather on my own in aerodynamics and not being committed to any rigid programme of research, I have followed my bent to explore unorthodox paths of experiment, the results of which I present with some diffidence in the hope that engineers may pursue them further with better equipment. I am afraid I have not gone deeply into the vexed question of the efficiency—in the engineering sense—of the devices I am going to describe to you, since, as a physicist that—nevertheless, important—aspect of the question does not interest me.

I. ACCELERATED BOUNDARY LAYERS.

The boundary layer concept introduced by Prandtl envisages a layer of fluid bathing a solid boundary beneath the potential flow and subject to similar laws to those which Osborne Reynolds first derived for the flow in a pipe. Within this layer the velocity falls rapidly from its external value to zero at the surface,

so subjecting the layer to considerable shearing force that, even if it commences at the nose of an obstacle as a laminar layer, it eventually becomes turbulent when the local Reynolds number exceeds a critical value.

The other factor in the boundary layer which leads to breakaway and eddying is inertia. This acts noticeably where the fluid is unable to follow sharp turns and convexities in the solid wall.

Some of the earliest and most successful attempts at control in the boundary layer aimed at the inhibition of this break up by pushing or pulling the fluid round the bluff portions of the obstacle. I propose to outline these in this section of my paper. They all aim at reducing the eddy-making resistance and leave the profile drag almost unchanged.

Schrenck (1) was the originator and most persistent exponent of devices which limited the extent of the eddying wake through suction in the rear portion of a model. In his earliest experiments he used a sphere one foot in diameter, mounted in a wind channel and having ring-shaped slots contrived in the rear half,

FIG. 1.

FIG. 2.

from which air was exhausted by way of the hollow tube of the force balance through a pump to the outside air. Smoke mixed with the air showed the extent of the turbulent wake; *cf.* Figs. 1 and 2 which are reproduced from his paper. The reduction in drag coefficient is shown in the following table:—

Reynolds number	2×10^5	3×10^5	4×10^5
Drag coefficient without suction ...	0.40	0.15	0.12
Drag coefficient with suction ...	0.09	0.08	0.12

The action of the slot causes, however, a certain instability in the wake which is the reason for the unsymmetrical pattern in the instantaneous smoke photograph (Fig. 2).

Since then (2) he has been experimenting with thick aerofoil sections stretching right across the channel and supported on the force balance from outside it. The pressure tubes pass directly out of the sides of the model to the pump so as to avoid uncertain resistances introduced by tubes exposed to the wind of the channel. A number of locations were tried for the suction slot. One of the most

favourable from the point of view of drag reduction is shown in the section on Fig. 3 together with the lift/drag curves for various suction powers. The latter are estimated as coefficients for correlation with the drag coefficients. Thus if S is the force of suction (=pressure drop through slot × area of slit); V the mean channel speed; A the projected surface of the aerofoil; and ρ the density of air, then

$$\text{The suction } S = k_s (\tfrac{1}{2}\rho V^2 A)$$
$$\text{and the drag } D = k_D (\tfrac{1}{2}\rho V^2 A).$$
$$\text{The total resistance coefficient } k = k_D + k_s.$$

On Fig. 3 the lift coefficient k_L is plotted against k_D and k for four values of k_s, *i.e.*, (*a*) 0.0008, (*b*) 0.003, (*c*) 0.008 and (*d*) 0.014. (The broken curve is the polar in the absence of suction.)

Lately, the same investigator has been trying the effect of suction on aerofoils having flaps, to obtain improved maximum lift coefficient near the ground, but I have been unable to trace any published results on full-scale aircraft.

Besides a diminution of vorticity in the wake due to the restriction imposed on the expansion of the boundary layer, a suction device also changes the general distribution of pressure round the model since it acts as a sink whose effects are experienced both fore and aft of the orifice. That is why the location of the slit, though relatively unimportant from the aspect of the prevention of turbulence in the boundary layer itself, does modify the reduction in drag which one would anticipate.

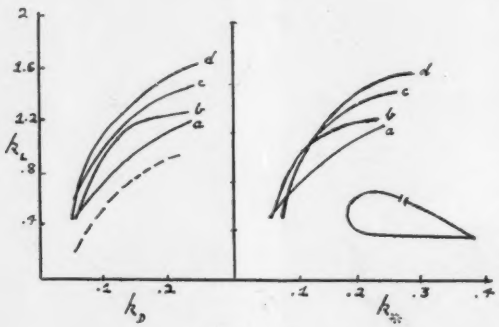


FIG. 3.

Other investigators have tried to increase the circulation and inhibit a breakaway by pumping air out of holes contrived in the fore part of the model and directed towards the tail. Reid and Bamber (3) studied a number of such devices experimentally, but came to the conclusion that suction is more economical than compression for drag reduction.

Abbott (4) constructed what he called an internal circulation model not requiring the use of a pump in which air was taken into the hollow interior through a slit near the front stagnation point and released through a number of narrower slits on the upper side beyond the section of maximum thickness. The useful range of lift/drag was so increased, but the maximum lift was reduced as compared with an untouched model of the same size and shape. Indeed it is probably impossible to increase the maximum lift without supplying additional kinetic energy to the air from a pump, or external booster of circulation. In this connection I need scarcely expatiate on the well-known Handley Page slot (5) and Townend ring (6) which will be familiar to readers of the Journal, and have to their credit a considerable period of successful full-scale operation. The latter device secures an improvement in the flow behind an obtuse tail by guiding vanes; the former may be regarded in the same light if the small front portion, cut off

by the slot, be regarded as the original model and the larger rear portion as an addition to it, having the object of cutting down turbulence in the wake, particularly at large angles of incidence.

The flow in the rear of a blunt stern may likewise be improved if it is hollowed out to form a channel for exhaust gas. Experimental investigation of the velocity and vorticity in the wake of a rocket shows this (7). Indeed, if the jet is expelled at a speed equal to that of the forward motion of the rocket so that the expelled gas is literally left standing, there is—in theory—no loss of energy in the wake. Unfortunately, the thrust under these conditions is nil, so that this ideal cannot be realised in practice. Nevertheless, rocket propulsion under more favourable circumstances offers possibilities in this direction at high speeds of propulsion.

Another means of providing lift and at the same time of reducing eddy drag is to be found in an application of the Magnus effect. When a cylinder is rotated at the same time as it is exposed to a steady wind not only does it experience a cross force in virtue of the induced circulation, but the wake being

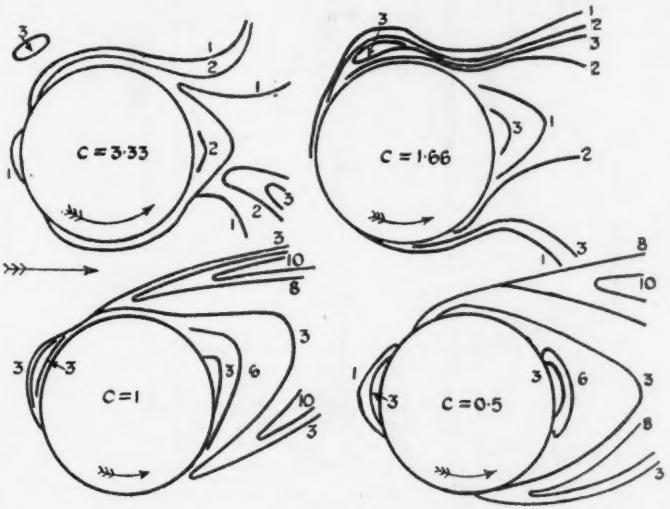


FIG. 4.

swept aside is reduced in extent. Traverses with a hot wire in connection with a vibration galvanometer across the wake of such a rotating cylinder show an inequality of vorticity on either side but overall reduction as compared to the stationary cylinder; this can be seen from the vorticity measurements which I published in an earlier paper (8), *cf.* Fig. 4. These were obtained in a wind channel with the cylinder rotating at a peripheral speed of 200ft. per min.; c represents the ratio of peripheral speed to stream velocity. The contours are of equal magnitude of velocity fluctuation. By using a pair of cylinders rotating side by side in opposite directions one could secure the reduction in eddying wake without the veering of the stream which is a concomitant of the cross force or lift.

A number of experimenters have, following Zijnen (9), fitted the rotor with a streamline tail to reduce the eddying still further while retaining the Magnus circulation and lift. I believe that full-scale aeroplanes have been essayed with built-in rotors in place of wings, but with what success I know not.

11. Heated Boundary Layers.

Instead of retaining a thin boundary layer by one or other of the devices described in the first section, we may keep down the local Reynolds number in the layer by an appropriate increase in the mean (kinematic) viscosity in the layer. The obvious way to accomplish this is to warm the air in the immediate proximity of the solid by heating the walls of the latter, but before describing my experiments in this direction I would like to refer to some attempts to

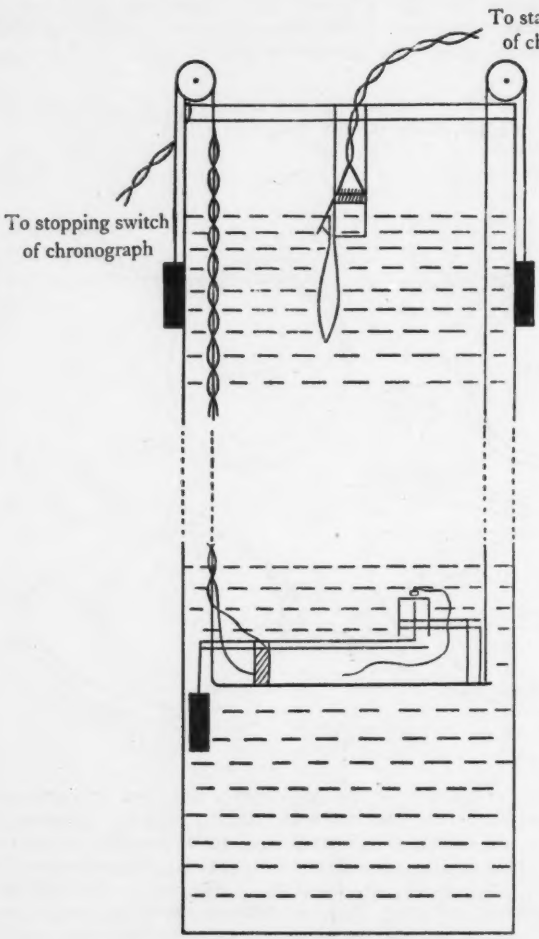


Fig. 5.

lubricate the layer in the more literal meaning of the word. This can scarcely be carried out within the domain of aerodynamics, but it is fairly easy to apply a thin film of oil to the surface of a model moving through water. One of the difficulties encountered is that, of course, the oil film is gradually sheared off the model, which prevents observations over a long trajectory. The resistance of the lubricated models was therefore determined from displacement : time graphs

of the motion of free fall in a tank of water. A tank 8ft. high and 1ft. 6in. square was available and was equipped with starting and stopping devices for the object whose fall was to be investigated. The former was an electrically operated clip; the latter consisted of a stage supporting a pivoted gauze network which broke an electrical contact directly the model hit it. The two contacts—starting and stopping—were connected to a Wood's chronograph, capable of reading to 0.002 sec. (Fig. 5). The two models were of wood, loaded in the nose. Occasionally they would perform a curved trajectory; but the readings were repeated until a minimum time was obtained. The times of fall with the stage at various levels were determined and from these the terminal velocity

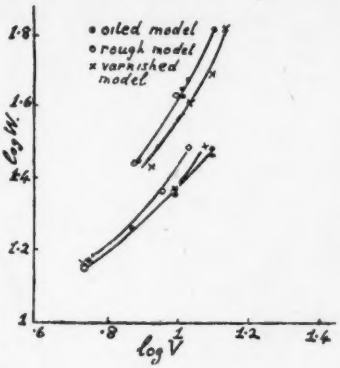
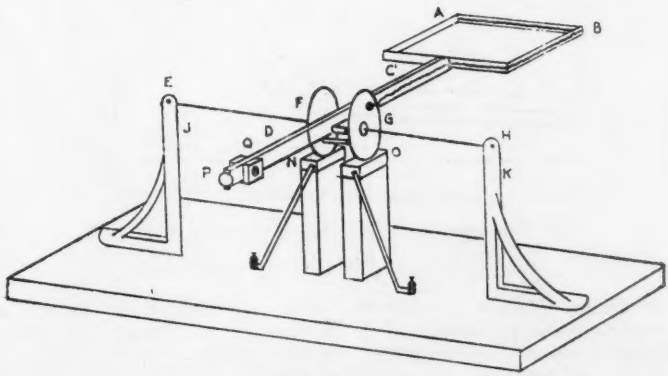


FIG 6.



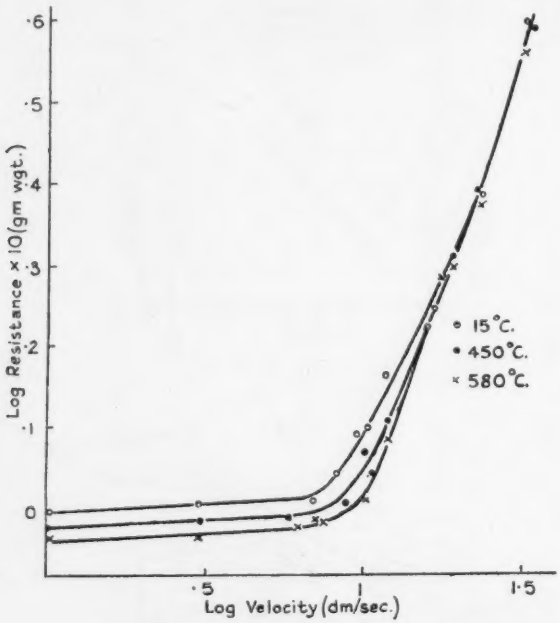
Force balance.

FIG. 7.

deduced. The displacement: time curves were obtained for three conditions of surface, (*a*) rough, (*b*) smoothed and polished, (*c*) greased with thin oil. (The work was actually undertaken to test a theory, current among certain biologists, that fishes have an abnormally low resistance to locomotion in virtue of the mucus lining on their bodies (10).) When the terminal velocity is reached the weight of the model (in water) balances its resistance. The results are accordingly exhibited in the form of curves of log. weight against log. terminal velocity (Fig. 6). It is apparent that these experiments gave no evidence of reduction in drag on

greasing, though actually the motion was entirely laminar at the low speeds concerned.

Passing on to the experiments on the drag of heated cylinders (11), consideration must first be given to the method of heating and of measurement of the forces in a wind channel. Hollow tubes of vitreosil were wound internally with spiral heating coils, the tubes having external diameters, 0.65, 1.3, 2.6 and 15.6 cm. The change in the aerodynamic forces on the thin cylinders associated with the heating was expected to be small, so that not only had the heat supply to be large, involving the use of electric power up to one kilowatt, but the force balance had to be very sensitive. Considerable thought was given to the



Resistance of 0·65 cm. cylinder (hot and cold).

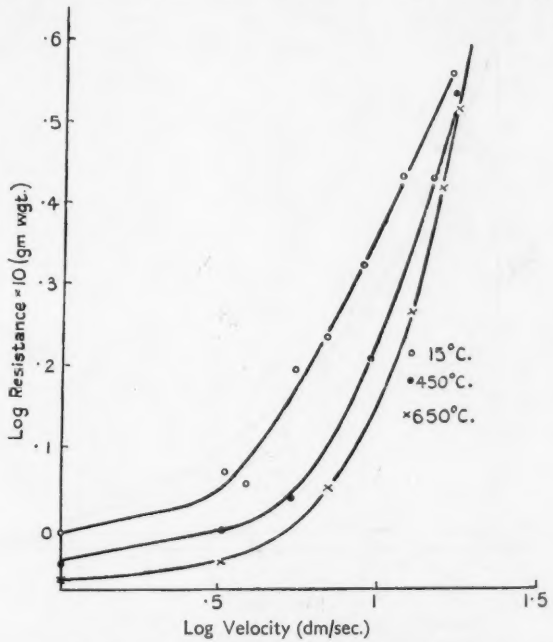
FIG. 8.

problem of designing such a balance to allow the leading in of large currents without variation due to deflection of the balance, and finally the form shown in Fig. 7 was adopted for all but the largest cylinder.

The cylinder AB rests on an aluminium frame rigidly attached to the balance beam CD. The pivot of the beam is that formed by the junction of the two wires EF, GH, which may be given tension and torsion through the operation of the wing nuts on the stanchions J, K. The inner ends F and G of these two wires are soldered to the centres of two discs which are in turn attached to the balance beam through ebonite distance pieces. The discs float in the mercury cups N, O, to which the current leads are taken. From the discs the current passes to the heating element through the balance beam and back through an insulated wire laid alongside it. Deflection of the balance by small forces is measured through the intervention of the mirror P and the usual lamp and scale. Larger forces are balanced by a re-setting of counterpoises such as Q along the calibrated beam. In measuring very small forces (of the order of

0.1 gm. wgt.) the instrument was used as a Threlfall balance, *i.e.*, the counterpoise was set in a little too far for equilibrium and the suspension wires twisted until the beam returned to the horizontal, any change in the aerodynamic force being then indicated by the spot of light on the scale. Under these conditions, the balance is very sensitive and may become unstable if one tries to push the sensitivity too far.

The cylinders were introduced into a 2ft. vertical wind channel so that the frame and balance lay outside. The air was sucked through the channel downwards against the natural convection current. Results of drag measurements on the 0.65 and 1.3 cm. cylinders both hot and cold are given in Figs. 8 and 9 respectively. After the natural convection current—which gives the cylinders an apparent negative drag—has been neutralised, the slope of the resistance velocity



Resistance of 1·3 cm. cylinder (hot and cold).

FIG. 9.

curve for the hot cylinder remains low for longer than that of the cold one. At values of Vd exceeding 300, however, the curves run together. The 15 cm. cylinder was then tested, as it would give Reynolds numbers near the second critical region (10^5) where the drag coefficient normally falls. This region could not be completely covered in my channel and of course there is a considerable wall interference on such a large cylinder, but the results in the table below at least indicate that the beginning of the drop in drag coefficient is delayed for the hot cylinder after it has begun for the cold one.

Velocity	250	355	440	620	710	750
Drag (cold)	20	40	60	110	140	150
Drag/vel.^{2}	3.1	3.2	3.15	2.9	2.8	2.7
Drag (hot)	20	40	60	115	150	170
Drag/vel.^{2}	3.1	3.2	3.15	3.0	3.0	3.0

There is, of course, a close analogy between the processes by which heat and momentum are transferred from a moving body, both drag and heat loss being capable of representation as a function of Reynolds number. It is rather difficult to compute drag coefficients in terms of Reynolds number when the boundary layer is heated since an uncertainty exists as to the appropriate value of this criterion. One can, however, derive some useful information by exploring the temperature field round the cylinder and comparing it with the velocity field. In my experiments I used thermo-couples to measure this temperature, and show the results along a horizontal plane through the axis of the cylinder on Fig. 10. The non-dimensional distance x is a function of Peclét's number P $(=Vrc/k$ where c is the thermal capacity per unit volume and k is the thermal conductivity

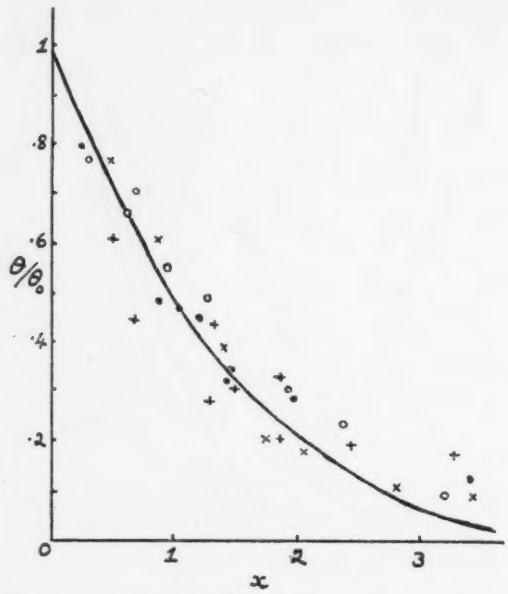


FIG 10.

of the air). For the median plane of the cylinder $x=(d/r)\sqrt{(P/2)}$ and the solution obtained by Piercy and Winny (12) for the temperature distribution is

$$\theta/\theta_0=(2/\sqrt{\pi})\int_x^\infty e^{-x^2}dx$$

θ being the temperature excess at a distance d from the surface, θ_0 that at the surface itself. When x is large $\theta/\theta_0=e^{-x^2}/(x\sqrt{\pi})$. This curve is shown on Fig. 10. The points are experimental, the four cylinders being distinguished by different types of dot. The boundary layer of velocity indicated by the rising gradient extends to a depth at which the temperature has fallen to roughly half the surface value. (There is again the difficulty of fixing on a value of P for the boundary layer. In calculating data for the figure, the value P corresponding to the mean value of the temperature of the layer has been selected.) Although there are discrepancies between the theoretical and experimental temperatures far out from the surface, there is fair agreement down to $x=2$, at which a common value 0.2 for θ/θ_0 is reached. Defining the thickness t of the boundary

layer to correspond to this value of x, we find—in terms of the Reynolds number of the cylinder:—

$$t/r = 2/\sqrt{P} = (7/3)\sqrt{(rV/\nu)} \quad . \quad . \quad . \quad . \quad (1)$$

Change in the type of flow should then be expected at a constant value of t/r, as the temperature of the cylinder is changed. In particular, I have endeavoured to read off the (lower) critical velocity from the drag curves, calculate t/r from this last formula and show that—within experimental error—it is independent of the temperature excess.

r	θ_0	Critical V	Critical t from (1)	t/r
0.325 cm.	450°C.	70 cm./sec.	0.093 cm.	0.28
	580°C.	90 cm./sec.	0.097 cm.	0.30
0.65 cm.	450°C.	40 cm./sec.	0.17 cm.	0.26
	650°C.	55 cm./sec.	0.185 cm.	0.28
1.3 cm.	650°C.	40 cm./sec.	0.31 cm.	0.24

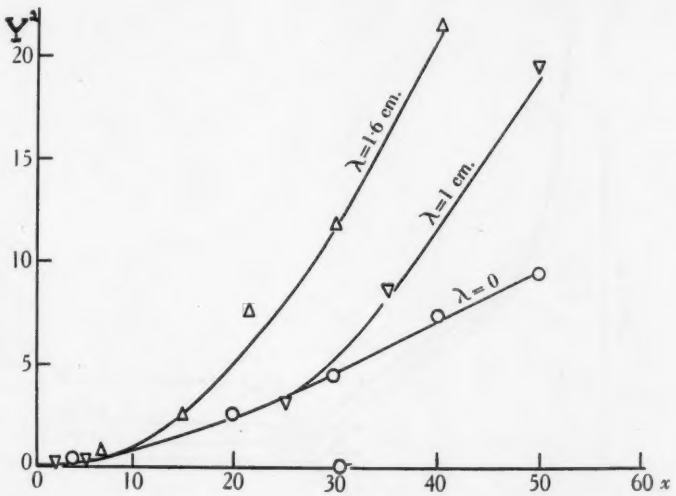


FIG. 11.

In these measurements on circular cylinders I have assumed that the bulk of the drag is due to eddy-making resistance. As far as *skin friction* is concerned, heating the boundary layer should increase the drag coefficient, since it lowers the local Reynolds number. This might be apparent on streamline struts with laminar flow.

III. PERIODIC BOUNDARY LAYERS.

Yet a third way is open to us to modify the state of affairs in the boundary layer. In this we endeavour to substitute for the disorder of turbulence, if and when it occurs, an ordered oscillation of determined frequency and amplitude. The distribution of mean velocity in turbulent flow is in fact so much like that which can be obtained by superposing a periodic ripple on a laminar type of flow as to lend support for Rayleigh's view of this state as engendered by the propagation of oscillations of finite amplitude from the solid boundary into an erstwhile steady stream.

One type of such flow arises when a fluid is constrained to follow a solid wall of sinusoidal surface (13). For instance, if a corrugated plate is placed in a

channel edge-on to a stream, the corrugations act as an elemental form of roughness of prescribed amplitude and wave length. Both factors influence the subsequent career of the boundary layer. If the ratio of amplitude to wave length be kept constant while both are increased—within limits—turbulence diffuses more rapidly out into the stream passing over the plate. This is brought out by some water channel experiments in which the diffusion of turbulence was indicated by the rate of dispersion of a dye let in along the leading edge of the plate. On Fig. 11 these rates are pictured as graphs of the mean excursion of a fluid outward along the normal for a given drift with the stream; Y^2 being the mean square deviation and x distance along the plate, while λ represents the wave length of the corrugations. The rapid increase in the slope of the $Y^2 : x$ curves as the tail is approached indicates the addition of vorticity to the stream emanating from the boundary. This rate is roughly proportional to λ. The plates were then hung up in the vertical wind channel and their resistance coefficients determined as a function of Reynolds number (Fig. 12). These results fall into line with those

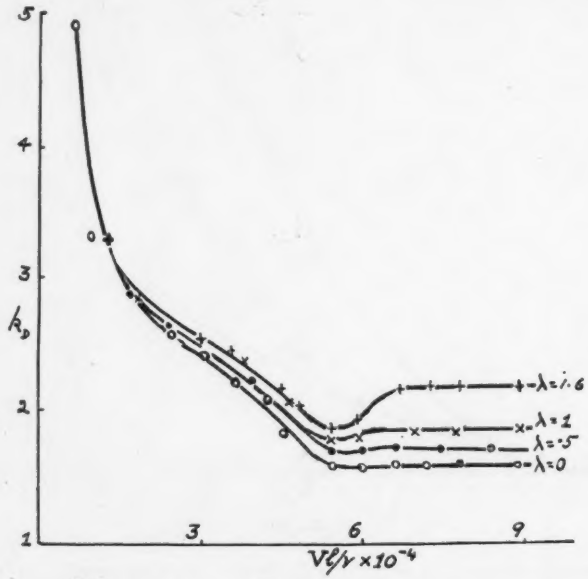


FIG. 12.

on plates and spheres roughened with graded sand grains and the resistance of pipes in which pulsating flow at a fixed frequency takes place (14, 15). Of course, more particularly in the case of a sphere the position of the sinusoidal rugosities may become very important for determining the type of flow. I have not studied this point experimentally; my object being to connect the resistance with the frequency of the crests encountered by the fluid in passing over the plate, which was accordingly corrugated equally over the whole of its exposed surface.

If a smooth plate or aerofoil is flexible, a sinusoidal boundary layer may be set up along it either by its natural oscillation in the wind or by giving one end a small simple harmonic motion transverse to the direction of the stream. As this end vibrates waves will travel along the flexible lamina and at the same time, the nose will meet the stream at a varying angle of incidence. I have measured the resistance of a flexible rubber flag in my vertical wind channel. The axis of the channel had to be vertical in order that the lamina, supported on the arm

of a horizontal balance, could hang vertical. The scheme is shown in Fig. 13. The oscillation of the flag stalk (S) was effected by making the stalk a thin steel rod of streamline section and fixing it near an electro-magnet (M) rigidly clamped to the balance beam (B). A dashpot (D) prevented vibration being imparted to

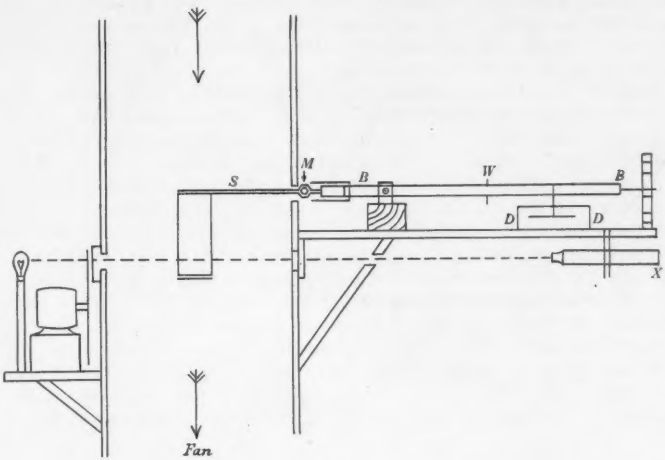


FIG. 13.

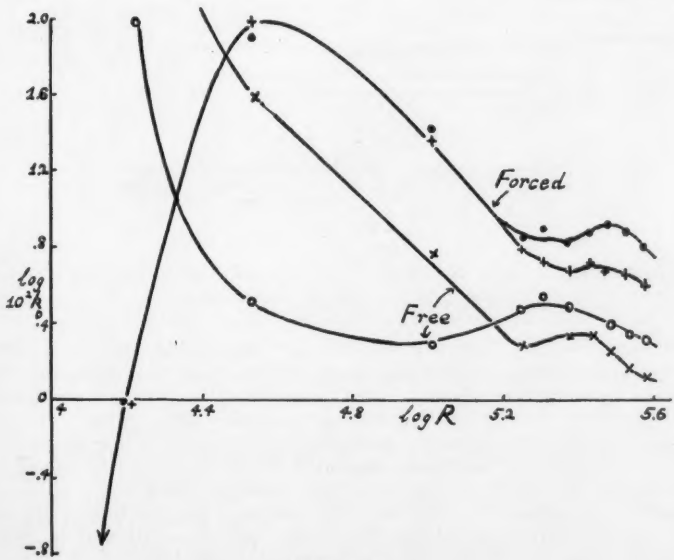


FIG. 14.

the balance beam. The electro-magnet was fed from an intermittent current whose frequency could be varied between 20 and 50 cycles per sec., thus vibrating the head of the model at a constant frequency and amplitude, depending on the strength of the current supplied. The rubber was occasionally loaded at its

lower end to increase its natural frequency of vibration. In order to measure the velocity of waves along the strip it was illuminated intermittently by a ray of light shining through the slits in the stroboscopic disc and window shown on the left of the figure, and observed through the telescope beneath the balance table. Actually it was the length of the waves travelling along the rubber which was measured in this way; knowing the frequency, the velocity of the waves along the rubber was calculated. At zero resistance, these corresponded roughly with the channel speed, but decreased as the resistance went up. Considered as a simple machine for transferring energy from the oscillator to the fluid, the efficiency may be derived as follows:—Let the mass of fluid set in motion per second—dependent mainly on the amplitude of oscillation—be mw, so that w is the velocity of waves along the model, while v is the speed of advance. Then the propulsive force = change of momentum per sec. $= m(w-v)$. The energy usefully employed is $mwv(w-v)$ per sec. while the kinetic energy rejected in the discharge is $\frac{1}{2} mw\{(w-v)^2+2v(w-v)\}$. The theoretical efficiency is then $2v(w-v)/(w^2-v^2)=2v/(w+v)$. The actual efficiency will be less by an amount dependent on the energy used in making vortices. Carrick (16) has calculated this for the case of a rigid plate given a simple harmonically varying tilt. The ratio of the energy dissipated in the wake to that used in maintaining the oscillations can be expressed in terms of a non-dimensional parameter v/nd where n is the frequency of the flapping and d a linear dimension of the model. Taking the energy input as proportional to $(an)^2$ when the oscillation is of amplitude a, and the resistance as being done entirely at the expense of the energy communicated to the stream, the curves of resistance at constant input plotted

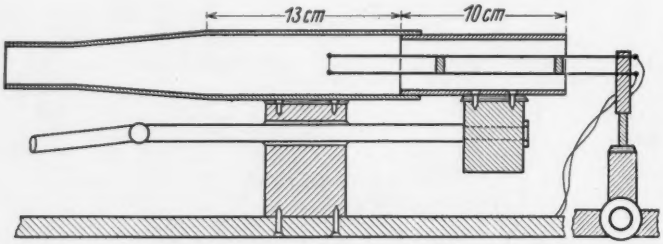


FIG. 15.

against v/nd which I have obtained (Fig. 14) tally with Carrick's theoretical curves. It will be noted that, as was to be expected, a negative resistance or propulsion is obtained at low values of v/nd.

Measurements of this type are not only of importance in connection with flapping flight, but recur in the Katzmayr effect, viz., the reduction of drag experienced by an aerofoil when, instead of meeting the air at a fixed angle of attack, it is given a see-saw motion through a small angle. Theory shows that the reduction will be most apparent when the object is of such a shape that the lift varies rapidly with the angle of attack and this is confirmed by model experiments, though I do not think any attempts have yet been made to apply the Katzmayr effect to full-scale aviation. The matter is also of interest in connection with the flight of birds and the locomotion of fishes. It was in fact from the last aspect that I made the measurements just described.

In a research some years ago on what we called "Synthetic turbulence," Dr. Tyler and I studied the effect of transmitting periodic waves into a pipe (aspirated at sub-critical speeds) from a section of the wall which was given a small simple harmonic motion parallel to the direction of flow (17). Fig. 15 shows the apparatus. The periodic boundary layer was produced by an electric motor

which moved the hollow piston to and fro on the end of a long connecting rod which could be given a stroke of specified value. The frequency was measured by a stroboscopic disc on the axle of the motor, illuminated from a neon lamp on the A.C. mains. The fixed part of the tube, slightly wider than the piston, was joined at its narrow end to an aspirator. The hot wire detector on its adjustable fork served to measure the turbulence induced at any point of the tube, being connected through a transformer to a tuned vibration galvanometer.

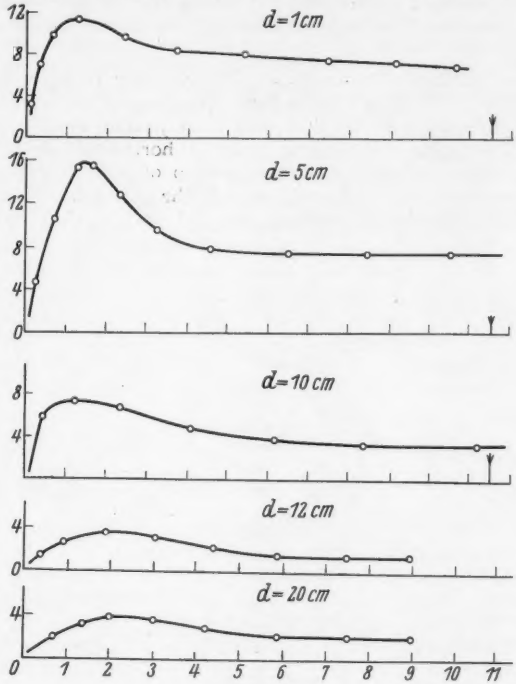


FIG. 16.

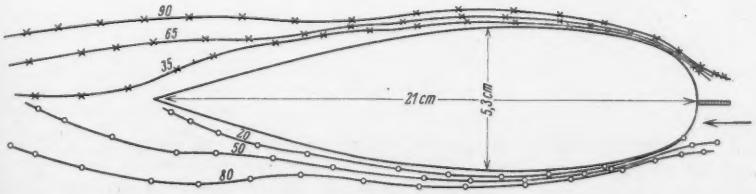


FIG. 17.

It was calibrated at each frequency by being vibrated in still air on the cross-head of the little reciprocating engine. Actually the response of the galvanometer in such circumstances depends not only on the amplitude of the velocity fluctuation, but also on the mean velocity about which this fluctuation takes place. A correction was made on that account when the aspirator was in action.

Fig. 16 gives results of velocity fluctuations with the piston working at a frequency of 25 cycles per second while a steady current of 25 ft./min. was

aspirated through the tube, for various distances d from the centre of the piston. The vorticity engendered by the inexorable movement of the boundary wall into the erstwhile steady stream (except for a small rapidly damped fluctuation probably arising at the entry) spreads out into the stream as a damped progressive wave and gradually permeates the whole stream, although at first a marked peak of disturbance is apparent near the wall of the tube. This type of diffusion from a periodic motion of the boundary wall thus falls into line with that in the water channel from a corrugated plate (Fig. 11) where the oscillation arises from the passage of the boundary layer over a Liliputian mountain range of equi-distant peaks.

As we had thus successfully simulated turbulent flow in pipes by superposing a periodic boundary layer on a steady flow, we thought we would next try this form of artificial turbulence in the flow past aerodynamic models, *i.e.*, a streamlined strut and a circular cylinder, spanning a horizontal 18in. wind channel. At the front stagnation point of the strut a strip of card (1 × 18 × 0.1 cm.) was mounted on the ends of two steel reeds outside the channel. These could be set in synchronous vibration by electro-magnets fed with A.C. at 11.5 cycles per

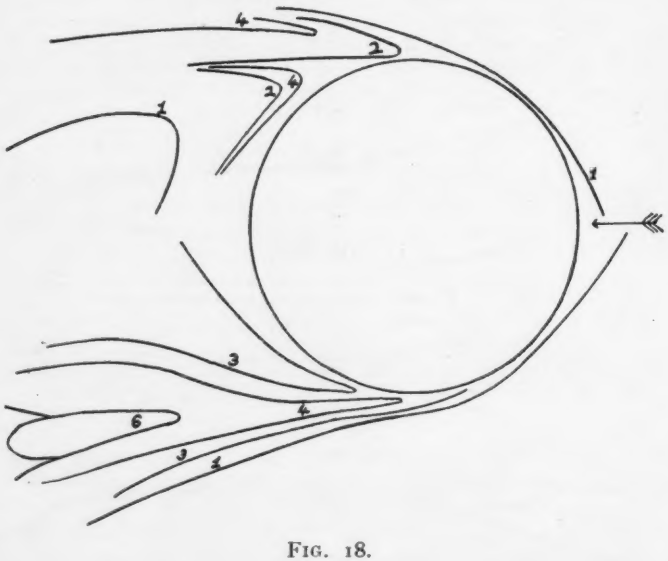


FIG. 18.

second, sufficiently low in frequency to move the whole strip up and down through an amplitude of 1 cm. Fig. 17 shows contours of *mean* velocity round the strut both with—lower half—and without—upper half—the periodic disturbance at the nose. The actual change in the configuration of the velocity field is not great, but I suspect that this is because—as Dr. Piercy and I have shown elsewhere (18)—there is a tendency for the *natural* turbulence arising at the front stagnation point of a cylinder to be damped out before it gets far round the surface, so that we had merely succeeded in enhancing the local turbulence at the nose by the action of the vibrating strip.

The experiment with a circular cylinder produced a more profound change in the flow. The one inch cylinder was oscillated as a whole about its axis through a small angle with a frequency of 25 oscillations per second, and the distribution

of *velocity fluctuation* measured all round it. These are shown on Fig. 18 (upper half—without; lower—with oscillation) as contours of equal amplitude of fluctuation with a channel speed of 800ft. per min. The vorticity is much accentuated at such speeds that the *stationary* cylinder would give rise to vortices in synchronism with the enforced vibrations of the cylinder surface. This is nearly the case under the conditions pertinent to the contours shown in the lower half of the figure. At velocities which would produce a higher aeolian frequency (given by $V/nD=5$, where n is the frequency of the vortex production and D the diameter of the cylinder) the wake becomes more restricted in width—as smoke photographs show—and the average vorticity is reduced, in spite of the higher channel speed, to something approaching the conditions shown in the upper half of the figure, namely, to those pertinent to a lower speed past the stationary cylinder.

Recently, I have confirmed this by measurements of the drag of a one inch cylinder in angular oscillation. The armature of the synchronous motor on the axle of the cylinder was restrained by a spring in such a position that on connecting to the A.C. supply it " hunted " about an equilibrium position through a small arc (about 10 degrees). The interesting point about the results—some of which are given in the table below—is that the resistance of the vibrating cylinder is reduced, in virtue of the artificially engendered turbulence, below that of the stationary cylinder, as long as the Strouhal number (V/nD) of the cylinder is sufficiently high to obviate resonance of the oscillation with the vortices. The latter condition is not satisfied by the first column in the table. Notice that the reduction starts at comparatively low Reynolds numbers.

Velocity	300	425	720	1000	1200 ft./min.
Drag, normal ...	5	10.5	30	58	84 gm. wgt.
Drag, in vibration...	6	10.5	29.5	56	80 gm. wgt.
Reynolds number ...	2.5	3.5	6	8.35	10×10^3

As my means of oscillating the cylinder was rather inefficient, I have not attempted to express the drag reduction in terms of input of energy, but simply to record the " effect " in the hope that someone will be able to make use of it on an engineering scale. I believe that cases are on record of wings having their lift/drag characteristics improved through the accidental looseness of the fabric and consequent increased flexibility. The present results appear to have a bearing on such questions.

References.

1. Schrenck. Z.F.M., 17, 366 (1926).
2. Schrenck. Luftfahrtforschung, 12, 11 (1935).
3. Reid and Bamber. ,N.A.C.A. Tech. Note No. 286.
4. Abbott. N.A.C.A. Tech. Note No. 371.
5. Handley Page. J. Roy. Aero. Soc., Aug., 1928.
6. Townend. J. Roy. Aero. Soc., 34, 813 (1930).
7. Richardson. J. Roy. Aero. Soc., 35, 29 (1931).
8. Richardson. R. & M. No. 1368 (1931).
9. Zijnen. N.A.C.A. Tech. Note No. 411 (1926).
10. Richardson. J. expt. Biol., 13, 63 (1936).
11. Richardson. Phil. Mag., 7, 681 (1937).
12. Piercy and Winny. Phil. Mag., 16, 390 (1933).
13. Richardson. Proc. Phys. Soc., 49, 479 (1937).
14. Fage and Warsap. R. & M. 1283 (1929).
15. Estel. Inaugural Dissertation, Leipzig (1936).
16. Carrick. N.A.C.A. Report No. 567 (1936).
17. Richardson and Tyler. Phys. Z., 13, 509 (1931).
18. Piercy and Richardson. Phil. Mag., 9, 1038 (1930).

Note.—Figs. 1 and 2 are reproduced from the Zeitschrift für Flugtechnik; Figs. 7, 8, 9, and 10 from the Philosophical Magazine; Fig. 4 from a Report published by the Aeronautical Research Committee; Figs. 17 and 18 from the Physikalische Zeitschrift.

Discussion.

The Chairman: He thanked Dr. Richardson for his informative and intensely interesting paper. Experiments such as had been described, carried out with very simple apparatus, often led to the discovery of new phenomena or started a train of thought which ultimately brought valuable results and benefited aviation generally. Mr. Relf was particularly interested in the experiment of oiling a surface. The enormous speed supposed to be attained by some fish was often attributed to some peculiarity of the surface of the living fish. He wished Dr. Richardson had been able to carry out his experiments with a considerably higher Reynolds number, although he doubted whether, even then, any marked effect, due to " lubricating " the surface, would be found.

Dr. N. A. V. Piercy (*Fellow*): Aeronautics had always owed much to physicists, not only to those who, fortunately, were continuously at work on the subject, but also to physicists who brought forward new ideas of aeronautical interest only less frequently, in the midst of their other work, as was the case that evening. There was a fairly prevalent view that aircraft wasted energy unduly. He did not subscribe to that view, or at any rate felt that improvement had now almost reached a stage when great savings would call for fundamental changes. Experiments, such as the lecturer had described, were exploratory in regard to the directions in which the possibility of fundamental improvement might lie. Those with heated cylinders, for example, were interesting in relation to phenomena occurring at the bottom of the boundary layer which were imperfectly understood. It was not envisaged that aeroplane designers would ever respond to the adoption of heated helium in airships by introducing red hot wings. But it was nevertheless of importance to know, for example, whether heating a surface sufficiently would cause air molecules to bounce off like tennis balls instead of clinging like cleavers. Some tests made some years ago on hot aerofoils were unproductive of results, but the temperature available at the time was too low, and he would like to ask the lecturer why he did not now carry on until a melt nearly occurred. Again it would appear, at first sight, more profitable to experiment with a thin flat section rather than with a rounded one; to look for effects on skin friction rather than on form drag.

Referring to the theory of heat convection from cylinders of mathematical profiles put forward by Dr. Winny and himself in 1933, Dr. Piercy was naturally very interested in the comparative experiments carried out by the lecturer. The check had turned out exceedingly well; it was difficult to see that the eventual deviation was due to radiation, being what one would expect through the exclusion of viscosity from the fluid. The theory bore a somewhat similar relationship to fact as approximations according to Oseen's equation at intermediate Reynolds numbers would bear to solutions of Prandtl's boundary layer equations in a more familiar field; the heat boundary layer predicted was bound to be rather too thin and the convection rather too great. The theory was developed, not so much with the intention of predicting physical results (though as the figure showed, it succeeded in doing so), as with that of providing a very convenient and elastic method of calculation to which an empirical factor could be added before application to practice. But, perhaps, radiation losses were especially important in the lecturer's experiments?

Another question he would like to ask Dr. Richardson, in view of his experiments, was just how much basis of fact there might be in the prevalent idea that fish were speedy. That their acceleration from rest was great one knew to one's cost, but that was another matter. Had he found fish with high steady speeds to exist outside anglers' tales?

Mr. A. Fage (*Fellow*): With reference to the experiments on falling bodies, the lecturer said that the motion was laminar, and if this were so, the resistance should vary as $V^{1.5}$. This appeared to be the case for the body having the higher resistance, but for the other body the resistance appeared to vary as V. Mr. Fage

then referred to the experiments on heated cylinders, in which a stream of air was sucked downwards through a tunnel, against the natural convection current, and he said he was interested to know how the correction for the convection current with the wind on was measured.

Referring to the experiments on periodic boundary layers along a sinusoidal surface, the question was raised whether the disturbance in the fluid could be specified by the wave length of the corrugations. Would there not be a tendency for the boundary layer to break down in the hollows between the corrugations, and a reluctance of the fluid to follow the surface? Further, did the superposed motion in the oscillating-wall experiments become unstable and break down? Mr. Fage said he had recently determined a criterion for breakdown of laminar flow due to wall oscillation, and he would expect breakdown of laminar air flow to occur when the product of the square of the wall amplitude in feet and the frequency exceeded about 0.025. What was the value of this product for the experiments described in the paper?

THE CHAIRMAN: In his department of the National Physical Laboratory they were not at the moment carrying out very much work on the subject of the paper, but he understood that there had been experiments at Farnborough, and a few words from someone at that establishment would be welcome.

Mr. W. G. A. PERRING (*Associate Fellow*): Some years ago a certain amount of work had been done at Farnborough. This was at about the same time that Schrenk, working in Germany, was exploring the possibility of preventing break-away by suction. In the Farnborough experiments an attempt was made to delay the stalling of an aerofoil by the removal or discharge of air through slots in its upper surface, and it was found that by the application of either of these methods the stall could be delayed. At the time of these experiments, however, high lift coefficients were not so essential as they are now, and the control at the stall afforded by the fitting of say a leading edge slot had most of the merits of the boundary manipulation scheme without the attendant disadvantage of having to provide power for its operation.

Since those early tests nothing was done until a year or so ago, when an attempt was made to bring about a reduction of drag by the removal of part or all of the boundary layer formed on a surface. These experiments were carried out on pipes and simple flat surfaces, and suctions were applied to the surface (*a*) to control the transition from laminar to turbulent flow, in an attempt to maintain the laminar layer, thereby lowering the local skin frictional coefficient and (*b*) to remove the boundary, and re-energise the boundary fluid so that the wake ordinarily formed behind a moving surface would be completely eliminated. All attempts to control the transition and maintain laminar flow conditions had so far failed; the application of suction had, in fact, brought about an effect opposite to that desired, in that it invariably caused an earlier transition to turbulent conditions than was the case without applied suction. It was thought that this failure to maintain laminar conditions was due to the " standing " periodic disturbance introduced by the suction applied to the suction slots. The conditions set up in their tests were very analogous to those which had formed the subject of some of Dr. Richardson's investigations.

In regard to (*b*) it was found that, by the withdrawal of a certain amount of the turbulent wake into the surface, it was possible to bring about a reduction in the net drag, provided that the fluid withdrawn through the surface would be energised without loss.

More recently, said Mr. Perring, they had been interesting themselves in the manipulation of the boundary layer from the point of view of improving the characteristics of a wing.

Experiments in Germany had shown that it was possible to achieve lift coefficients rising to as high as $C_L = 3.5$ by suction methods. Such high lift coefficients, he was sure, would be attractive to any aeroplane designer provided they could

be obtained economically. There was a reasonable hope of our being able to do this, and experiments would be begun shortly at Farnborough on a wing with flaps, and suction slots, to explore the possibilities of various suction methods.

Anyone, said Mr. Perring, who had experimented with small models in wind tunnels would be aware of the difficulties introduced into the work by changes in the point at which transition from laminar to turbulent flow occurred. This uncertainty, especially with small models, tested at low Reynolds number, often made the interpretation of the tunnel results difficult and at times misleading. In some of their work the trouble had been avoided by deliberately establishing turbulent conditions at some point near the nose of the model under test. Two methods of achieving this had been developed. In one of them the turbulence was produced by the addition of a small thread secured to the surface of the body, while in the other, turbulence was introduced into the wind stream at some point ahead of the model under test, by the haphazard motion of a number of small flapping tabs. These tabs were located at the intersecting points of a wire mesh stretched across the tunnel, and their action was much the same as the single " forced " tab used by Dr. Richardson in some of his experiments.

Mr. J. V. Connolly (*Associate Fellow*) : He had been surprised, at first, to hear the references to the heating of the boundary layer; Dr. Richardson had approached very closely to a really good solution of the boundary layer control problem, although he had not actually reached it. Heating the boundary layer might work with a sphere. But when the surface of a streamlined body was heated, the opposite effect was obtained. In other words, one wanted to increase the Reynolds number of the boundary layer, and that was done not by heating the layer, but by introducing some fluid which would dose the boundary layer and increase the density or reduce the kinematic viscosity of the local flow.

The oil on the very small streamlined bodies probably changed the form of the bodies at the back, and possibly it would also change the actual displacement of the bodies, as compared with bodies on which there was no oil used. That would mask any possible reduction in the drag and the results must be inconclusive. Possibly Mr. Mills could give some of the interesting results he had obtained in regard to drag in experiments in which the boundary layer was dosed with carbon dioxide, the effect of which was to give a measurable reduction of drag in the wind tunnel. The meeting would be glad to have the benefit of his experience.

Mr. J. B. Mills: He would refer to some experiments at Sydney University, under Mr. Leech, in which the skin friction and total drag of a streamline body had been reduced by introducing carbon dioxide into the boundary layer, thus reducing the kinematic viscosity of the boundary layer to less than half that of the air in the wind tunnel. Reduction of the kinematic viscosity of the boundary layer had the effect of virtually increasing the Reynolds number of the body as a whole, and the body, being rather " simple minded," and not realising what was going on around it, naturally suffered a reduction in drag. For the substitution of an adulterant gas in the boundary layer in place of air alters the drag of the body to that which it would experience had it been moving in an atmosphere of the adulterant gas, as the body was streamline and the drag almost entirely skin friction. Considering it from the aspect of skin friction, the skin friction coefficient is proportional to the inverse of the square root of the Reynolds number for a laminar boundary layer and to the inverse of the fifth root of the Reynolds number for a turbulent layer. Hence a reduction in the kinematic viscosity of the boundary layer results in a reduction of the skin-frictional drag. A streamlined body of fineness ratio 3/1 was used for the experiments, and the gas introduced at the nose; the reduction in drag was consistently of the order of 15 per cent., which result had been expected from theory as the boundary layer was turbulent. The flow in the rather crude wind tunnel was turbulent as shown visibly by the introduction of smoke into the airstream, and there was a ring at the nose of the model. For a laminar boundary layer the

theoretical reduction in skin friction is of the order of 40 per cent. As both time and finance were limited, the experimenters were only able to arrive at the basic result that by introducing a fluid into the boundary layer to replace the normal fluid of the main stream, they could secure the changes in drag that would be expected from the theory.

Mr. W. E. Gray: He would like to comment on a statement that the efficiency of a rocket was zero when the jet velocity was equal to the speed of motion. He had always understood, and still thought, that the efficiency was then 100 per cent. He asked Dr. Richardson to elaborate the point.

He also criticised the reference, in 1938, to a cylindrical body as being an aerodynamic body.

(*Communicated*). Referring to the author's reference to the Handley Page slotted wing, and his idea of regarding the wing as reducing the wake behind the slot at high incidences, is there any evidence to show that it does this? In any case the idea seems rather fantastic, for it is the wake behind the wing that is of importance.

He thought that the author should have included in his list of references some recent comprehensive tests by the N.A.C.A. on a wing with air sucked from and blown over the upper surface.

Mr. A. V. Stephens (*Associate Fellow*): With reference to the statement in the paper that the boundary layer became turbulent at a certain local Reynolds number, he would like to mention some work at Cambridge on the measurement of the transition points in flight and in the tunnels: Although that work had continued for some time, the experimenters had yet to discover the proper value of that Reynolds number. Indeed, they were coming to the conclusion that there was no particular number at which transition would occur, even if the circumstances as regards pressure gradient, and so on, were very closely defined; they felt that the transition was at least affected, if not actually governed, by fluctuations in the laminar part of the layer, and they had a certain amount of evidence that such fluctuations were always present. It seemed that Dr. Richardson's experiments with oscillating plates and cylinders might have very illuminating results if he could discover what effects they had on transition. But he found it difficult to understand some of the figures. Were the changes of drag induced by moving transition forward or by changing the position of separation at the back of the body?

With regard to the experiment in which a flexible plate was used, he asked whether the boundary layer was turbulent or laminar. There were no results given for the turbulent boundary layer on a fixed plate, for comparison.

Finally, he wished to protest against the indiscriminate use of logarithmic plotting, particularly when the quantities to be represented were negative!

Mr. L. F. Fox: It seemed that Dr. Richardson's experiments on lubricating the outside of a streamlined body were rather similar to those described by Mr. Mills, except for the possible difference in the relative kinematic viscosities of the wind tunnel fluid and the lubricant. But Mr. Mills had reported a consistent decrease of drag, whereas Dr. Richardson's results were not quite consistent, there being a slight reduction in one case and a slight increase in the other. He asked whether the increase or decrease of drag depended on the shape of the body, and whether the shape of the body which was lubricated was a critical factor; if it were, the 15 per cent. gain referred to by Mr. Mills would not necessarily apply to all aerodynamic shapes.

Mr. A. A. Hall (*Contributed*): The presence of fluctuations of velocity in fluid flow is a matter of considerable interest, both from the viewpoint of the dissipation of energy by viscous action in micro-turbulence, and of the transition of boundary layer forms. Turbulent fluctuations are characterised by the presence of very high frequencies, the spectrum extending to several thousand cycles per second, and the small eddies which are responsible for the presence of these high

frequency components are also largely responsible for the dissipation of energy by viscous action. The fluctuations of velocity associated with the laminar boundary layer, however, have a more limited spectrum, the preponderant frequencies being considerably lower than those found in turbulent flow. The origin of these layer fluctuations is still unknown, but there is growing evidence that they are fundamentally connected with the laminar flow, and are not, as had been suggested, forced by turbulent fluctuations on the external stream. They have, therefore, become of some interest as a possible explanation of spontaneous transition, as distinct from forced transition, which has its origin in external disturbance, such as that associated with a turbulent stream.

It would be of interest if Dr. Richardson would specify the nature of the fluctuations recorded in Figs. 4 and 18. Whilst some of these fluctuations were recorded in the presence of a definite forced oscillation of fixed frequency, others were recorded in the free stream (top half, Fig. 18). In the latter case there can be no reason to suppose that the oscillations are of fixed frequency, and it is not clear that even in the presence of a forced oscillation it is correct to regard the resulting oscillations as being entirely of that frequency. In fact, the nature of the dissipation of the energy of fluctuation excludes this. In the top half of Fig. 18 a contour marked 1 is shown near the front of the body. Is this a fluctuation in the boundary layer, or is it outside? Are the amplitudes of fluctuations given statistical root mean square values, or have they other significance? The presence of turbulence in the wind stream is unavoidable without considerable care, and since this turbulence has a profound effect on experiments carried out in the wind stream, and particularly on fluctuations of velocity present, will Dr. Richardson specify the turbulence factors of his wind-tunnel?

In the lecture and in the discussion following it the effect of " lubricating " the boundary layer was mentioned. The lecturer stated that as far as skin-friction is concerned, heating the boundary layer should increase drag. It is undoubtedly true that heating the layer will increase the local friction drag coefficient, but it does not appear to follow that the drag itself will be increased, since the density is decreased. The actual effect to be expected seems to depend very much on the fundamental nature of the layer, and on the processes involved in the diffusion of fluids of differing physical properties. This point seems to be of particular importance in connection with the case of a boundary layer " doped " with carbon dioxide, to which reference was made at the lecture, in the discussion. In the case of a boundary layer on a hot surface or at high speed (when the layer of fluid near the surface will have an appreciable rise of temperature) the fluid will have continually varying physical properties.

However, if one takes the simpler question of regarding the effect of introducing heat at the surface, and the effect of introducing another fluid, as merely making a boundary layer of different physical properties, which are uniform, one arrives at results which disagree with the lecturer's statement, and also with the experiments carried out at Sydney University, to which reference was made in the discussion. In the case of laminar flow, for instance, the friction drag coefficient is proportional to $1/\sqrt{R}$ where R is the Reynolds number. The overall drag, which is proportional to ρC_F, where ρ is the fluid density, is thus given by

$$D \propto \rho C_F \propto \rho \sqrt{R} \propto \sqrt{\rho \mu},$$ μ being the fluid viscosity coefficient.

He found that, in heated air, the decrease in Reynolds number is offset by the decrease in density, and for laminar flow in air at 300°C. the friction drag of a plate is about 0.9 times its value in air at 15° C. It is realised that this simple calculation cannot represent the whole truth, since, as has been stated, the problem is one of great complexity, but it seems more legitimate to regard both the density and the viscosity as having changed than to take the drag as proportional to the drag coefficient, so neglecting density change.

Similar arguments can be applied to the experiments on the introduction of carbon dioxide. It was stated that a 15 per cent. reduction of drag was found,

and that this result was theoretically predicted. It seems, however, that in this case, in the absence of the full theoretical treatment, which is at present very difficult owing to complex factors involved, one would expect an increase in drag, since the increase of Reynolds number associated with a reduced kinematic viscosity is offset very considerably by the density of the carbon dioxide.

It appears that in the case of a full laminar boundary layer of the gas, the ratio of friction drag to the corresponding value in air would be 1.14, and in the case of the turbulent layer 1.3. The decrease of drag found in the Sydney experiments is not, therefore, entirely what would be expected, and one feels that the decrease was caused by an entirely different effect. It is possible that the introduction of the carbon dioxide so disturbed the flow as to cause transition of the laminar layer, whereas previously transition had not occurred, the laminar layer undergoing separation, with the consequent production of a large form drag. If transition were caused to precede this effect, the skin-friction would be increased, but the form drag would be decreased, with a probable decrease in the total drag, as recorded. It was stated in the discussion that in these experiments the layer was probably all turbulent on the grounds that the tunnel used was very turbulent. This is hardly a complete argument, since if the body used were sufficiently small, it could have a complete laminar layer despite the presence of large turbulence. A flat plate can have a laminar layer four inches long at 50 feet per second in the presence of 3 per cent. of turbulence, a value obtained even in a very bad tunnel only by deliberate introduction.

The statement, at the beginning of the lecture, that boundary layer transition takes place at a critical Reynolds number, is hardly correct. The writer has maintained a laminar layer on a flat plate, in the absence of pressure gradient, to a length Reynolds number of 2.5 millions, in a wind tunnel of very small turbulence. Dryden, in a tunnel of greater turbulence, reported a value of 1.1 millions. The average wind tunnel gives about one third of this. It appears that in this type of turbulence forced transition, the Reynolds number attained is critically dependent of the free stream turbulence. The Reynolds number attained when turbulence is apparently not responsible for transition is even more vague. There is, in fact, no evidence of a critical value.

Reply to the Discussion.

Before dealing with the detailed questions he would like to amplify what he had said in Section II, as this would save unnecessary repetition. In comparing the relative merits of experiments on heated and literally lubricated boundary layers one has to be aware of the difficulty of ascribing a unique value of ν to the former and of the unknown effects which the interfacial tension between the two distinct fluids may introduce in the latter. It is important to distinguish effects which may be ascribed to a pure pressure (ρV^2) from the true shear in the boundary layer and from convection drag, but it is not easy to do so. The injection itself must not cause an acceleration of the boundary layer. If the injected layer is thick and extends into the region of potential flow, then the model is being tested under practically the same conditions as if it were immersed in an infinite medium having the same properties as the injected fluid. He thought that the next step in these experiments should be the trial of lubricated layers of various depths using a lubricant of different viscosity to that of the extended medium, but having nearly the same density, and at higher speeds than those which had been used up to the present.

In reply to Dr. Piercy, he said that he suspected radiation as the chief influence which caused the small discrepancy between theory and experiment noted on Fig. 10, because when the thermo-couples were quite a long way from the cylinder they still recorded a temperature a few degrees above room temperature, even with the channel running. In collaboration with a biologist, he tried to measure the speed of a fish confined in a long narrow trough. The fish being " tickled "

into action, a cinematograph film had been taken of its passage along the tank. The maximum acceleration recorded was $1\frac{1}{2}$ft./sec.^{2}.

In answer to Mr. Fage, he was unable to account for the falling-off of the resistance of the smaller model (Fig. 6) from the $V^{1.5}$ law unless it were an error inherent in the free-fall method, as other experimenters, *e.g.*, Lunnon, had found a similar effect with falling spheres. The product a^2f ranged in these experiments up to 0.0025. He supposed that the shape of the entry would affect Mr. Fage's criterion.

He was very interested to hear of the experiments described by Mr. Perring and Mr. Mills, and hoped that their success would be continued.

In reply to Mr. Stephens, he imagined that the changes in drag to which he referred were caused by bringing the transition forward. Measurements were actually made on fixed plates at corresponding Reynolds numbers to the flexible ones which indicated that the boundary layer on the former was turbulent, but he could not say whether this was equally true of the flexible laminæ. While agreeing with the *caveat* on the use of logarithmic plotting, he said that the arbitrary scale of " resistance " in Figs. 8 and 9 actually was a scale of balance-weight positions, chosen so that the position of the weight corresponding to the cold cylinder in still air was represented by unity! By this bold step he had been able to retain the advantages of logarithmic plotting in spite of the negative values of the drag.

Mr. Gray was quite right about rocket efficiency, which was correctly given in the earlier paper (7). He had corrected this in the proof. As to his remarks on the slotted wing, one was surely entitled to regard the small forepart as the original model to which the main body of the wing had been appended, or *vice versa*. The phrase was used merely to point an analogy with the Townend ring. He knew of the N.A.C.A.'s work on wings with suction and compression prior to 1934, but had not seen a more recent publication on the subject.

In reply to Mr. Hall, he said that, of course, the simple arrangement of hot-wire coupled to a vibration galvanometer could only be used for measuring fluctuations when these were predominantly monotonal, and even then a correction was necessary for the mean speed about which the fluctuations took place. He had used this device for the measurements of Figs. 4 and 14 because he was primarily interested in the effect produced on the normal eddy frequency of a circular cylinder by rotating or oscillating it, as he believed that these were the fluctuations which contributed most to the resistance of the circular cylinder. The contours accordingly represent relative mean amplitudes at this frequency. He was afraid that they did not obtain precise measurements of the degree of turbulence in the channel at the time of making these experiments, but his recollection was that the contour " I " would represent little more in effect than the reading in the main stream, in the absence of the cylinder. He added that there was a fair amount of damping in the recording system, so that its response curve in respect of frequencies on either side of resonance was rather broad.

Mr. Hall's further remarks on the desirability of sorting out viscous effects from those due purely to density were endorsed by the lecturer (*vide supra*). In using the phrase " critical value of a local Reynolds number," he was speaking generally, and did not mean to imply that there was a determinate value for any particular case of fluid motion. This could never be so while the " thickness of the boundary layer " was an indeterminate quantity.

Finally, he wished to thank all those who had contributed to the discussion. As one speaker had suggested, the paper was intended to be stimulating and to encourage others to give their attention to this subject. He also had a more selfish reason for bringing the paper before the Society. He had hoped to receive some constructive criticism on his own efforts and suggestions for further work on these lines. This expectation he felt had been abundantly realised.

(On the motion of the Chairman, a hearty vote of thanks was accorded Dr. Richardson for his paper.)

ABSTRACTS FROM THE SCIENTIFIC AND TECHNICAL PRESS.

Issued by the
Directorates of Scientific Research and Technical Development, Air Ministry.
(Prepared by R.T.P.)

No. 58. AUGUST, 1938.

Army Co-operation as the Main Objective of the Air Force. (Rev. de l'Arm. de l'Air, No. 102, Jan., 1938, pp. 3-6. Available as translation No. 673.) (58/1 France.)

The principal object of war is to destroy the armed forces of the enemy. In the air, however, the enemy may try to evade a large scale engagement and the problem is therefore to force him to give battle. One way of achieving this is to attack ground targets of such importance that the enemy air force must necessarily intervene. On account of the differences in effective range of various types of aircraft, it may, however, not pay the attacker to strike at an objective too far behind the lines purely from this point of view. Tactical conditions are, however, improved if the target is nearer home and the author points out that by choosing the front line itself as the objective of the attack, the enemy is forced to intervene and a major aerial battle results. In the words of the author, " the ground battle aspirates the air force " and co-operation with the army is thus the principal objective. This co-operation must, however, be understood in its broadest sense and not limited to artillery range finding or raking trenches with machine guns from the air. It is rather an overwhelming attack on headquarters, railways, munition depots, rest camps, etc., all situated within or near the battle zone. Since no enemy territory is passed over, there is every chance of surprising the adversary and forcing him to intervene under what are to him unfavourable conditions.

The Training of the Aircraft Observer. (R. Thoumin, Rev. de l'Arm. de l'Air, No. 102, Jan., 1938, pp. 21-40. Available as Translation No. 498B.) (58/2 France.)

The aircraft observer has generally only a limited time available for studying the ground and it is therefore necessary that he concentrates his attention on essentials. He must know where to look and what to look for. It is extremely important that he should be able to form an opinion as to the appearance of the ground landscape to a soldier situated on the ground and he also must have sufficient training to appreciate the military possibilities of the territory over which he is flying. For this reason the author recommends a preliminary course in military geography so as to enable the observer to judge possible offensive and defensive positions and the particular manner in which certain territorial features will dominate others.

Once the possible positions of the enemy have been determined in this manner, the observer will look for definite evidence of enemy occupation. However well camouflaged, positions held by the enemy are bound to exhibit certain anomalies when viewed against the background of the normal landscape. In the words of the author: " The well trained observer will react almost automatically to such anomalies since they strike him like false notes in a symphony."

Obviously a considerable amount of flying experience is required to obtain this "automatic response," but much can be done by the careful study of selected aerial photographs. The author gives examples of such photographs, exhibiting various types of French scenery, and explains how by their means the observer is trained to look for essentials. It is hoped that by means of this kind of study the number of flying hours can be cut down.

The Training of the Air Force Officer. (Rev. de l'Arm. de l'Air, No. 102, Jan., 1938, pp. 85-6. Available as Translation No. 672.) (58/3 France.)

Although tactical instruction must necessarily be based on an official outlook, criticism by the student is invited and arrangements have been made for French officers to have official access to the Chief of the Air Staff as regards any suggestions concerning the employment of the Air Force.

The author is very keen to foster the spirit of team work amongst the students. The team should not be restricted to the officers of the same squadron doing similar work, but extend to civilians so as to cover a wide aspect (doctor, historian, engineer, artist, etc.).

In this way the outlook is widened and the critical faculty strengthened.

Lectures should be restricted as much as possible. Instead the officer should be induced to find out for himself and what is most important, put his thoughts on paper.

The author points out that at the Air Academie of Italy and Germany, both publicity and material rewards can be gained by the military author, whilst in France, only purely sporting achievements are rewarded.

World's Parachute Record (Delayed Opening). (P. Blu, l'Aeronautique, Vol. 20, No. 229, June, 1938, pp. 111-117.) (58/4 France.)

In March this year, the French parachutist J. Williams carried out a free drop of 11,175 m., the parachute opening 90 m. from the ground. The total time of descent amounted to 187 sec., the last 17 seconds corresponding to the functioning of the parachute. From the barograph records it appears that the rate of descent was practically constant at 75 m./sec. for the majority of the distance, slowing down to 40 m./sec. at an altitude of about 2,000 m. The terminal velocity was thus considerably less than the usually accepted figure for the human body (50 m./sec. at ground density and 80 m./sec. for a drop from 10,000 m.). The reason is that Williams had his arms extended. Medical examination of the parachutist showed no harmful after effects.

Previous to this record drop several practice jumps at lower altitudes were carried out and it is interesting to note that although the parachutist made every effort to land in the same region, and the meteorological conditions were similar the actual points of contact differed by 2-3 miles. From this it appears that the landing of parachute troops will require special sighting devices.

Control of Lighting in Buildings for A.A. Protection. (E. Bleser, Elektrotechnische Zeitschrift, Vol. 59, No. 13, 31/3/38, pp. 337-339.) (58/5 Germany.)

The author calls attention to a simple method of dimming the electric lights in a building by lowering the supply voltage.

In the case of alternating current supply, the voltage is easily lowered by a suitable transformer which is incorporated in the circuit by a master control in case of emergency. Preliminary trials will determine the decrease in supply voltage required (usually of the order of 25-45 per cent.).

In the case of direct current supply, the decrease in voltage has to be carried out by resistance and since in this case the actual drop will depend on the load, a hand adjustment will have to be provided.

The work carried out in buildings may necessitate the continuance of full illumination over restricted areas. These lamps will remain on the full supply

circuit and will be provided with tubular extension shades so as to concentrate the light in the required direction. If properly installed, ordinary sun blinds covering the windows will prevent any reflection to the outside of the building.

Italian Views on the German Air Force (from Ala d'Italia). (Inter. Avia., No. 561, 16/7/38, pp. 1-3.) (58/6 Italy.)

On March 1st, 1935, the German Air Force amounted to 250 machines. At the beginning of 1938 the estimated strength was 250 first line squadrons. Each squadron consists of nine aircraft supplemented by a first line reserve of three aircraft, a total of 3,000 aircraft, to which must be added 5,000 aircraft at schools; test centres and in air traffic, of which 700 can be used in front line service. The first line aircraft is of the following type:—

Type.	Designation.	Top Speed, m.p.h.	Range, miles.	Bombs, No.	Armament.
Bombers ...	He 111	310	930	4400	3 M.G.
	Ju 86	230	670	2200	3 M.G.
Dive Bombers	Hs 123	250	370	660	2 M.G.
	Hs 108	250	870	1100	1 M.G. and 1 cannon.
Fighters ...	Bf 109	310	370	—	3—4 M.G.
	He 112	302	685	130	4 M.G.
Reconnaissance	Do 17	300	930	1100	3 M.G.
	He 70	225	1300	660	2 M.G.
	Hs 122	175	600	—	2 M.G.

The author estimates the present annual output of the German industry at 5,000 aircraft, of which 50 per cent. are heavy types.

Cost of Training for Pilot's Licence and Cost of Practice Flight for Members of the N.S.F.K. (National Socialist Flying Corps). (Luftwissen, Vol. 5, No. 7, July, 1938, p. 246.) (58/7 Germany.)

The new regulations (April, 1938) have led to a considerable reduction in training cost, especially for the younger members of the N.S.F.K. Thus provided the applicant is below 23, physically fit, has not yet served in the army and has reached the required standard of preliminary training of the N.S.F.K. the following figures apply, on the understanding that the applicant will subsequently join the German Air Force:—

A2 Licence in 22 flying hours	RM. 200 (payable in instalments)
Every hour in excess	RM. 12
A1 Licence per hour training	RM. 15
A2-B1 ,, ,, ,, ...	RM. 15
B1-B2 ,, ,, ,, ...	RM. 18
PRACTICE FLIGHTS (ON CORRESPONDING AIRCRAFT) (REFRESHERS).	
A2 Licence holder, per hour	RM. 12
K1 ,, ,, ,, ...	RM. 12
B1 ,, ,, ,, ...	RM. 12
B2 ,, ,, ,, ...	RM. 18

For older applicants who do not give an undertaking to serve in the Air Force, a sliding scale applies ranging from two to five times the above rates.

The training for pilot's licence can only be carried out at one of nine Government Civil Aviation Flying Schools. Practice flights can be carried out either from the above schools or any N.S.F.K. aerodrome.

The Italian Air Force Manœuvres at Furbara in Connection with Hitler's Visit. (Luftwehr, Vol. 5, No. 6, 18/7/38, pp. 216-218.) (58/8 Italy.)

Over 300 aircraft took part in the manœuvres, an attack being staged on simulated harbour works and two ships at anchor.

The following types of aircraft participated:—

Bombers: Savoia S 81	}	Six regiments and two groups.
,, S 79		
Fiat Br 20		
Fighters: Fiat CR 32		Two groups.
Ground attack: Breda 65	}	One regiment.
AP 1	}	One group.
Reconnaissance: Romeo RO 37 ...	}	One group.
Cant Z 501		

(It appears that an Italian group consists of 16 aircraft, two groups forming a regiment.)

Altogether 98 tons of bombs were dropped in the 20 minutes the display lasted. Of special interest was a simulated bomb attack by fighters on bombers. The fighters crossed the path of the latter at an altitude of about 100 m., dropping their bombs so as to explode in the air immediately in front of the bombers. The explosion of these bombs was rendered visible by smoke puffs and it was noticed that in actual practice these bombs would either have destroyed the bombers or forced them to deviate from their course to such an extent that an effective attack on the ground target by the bomber would have been impossible.

A New Night Fire Control Apparatus for A.A. Artillery. (R. Schmitt, Luftwehr, Vol. 5, No. 6, 18/7/38, pp. 243-246.) (58/9 France.)

The article deals with the Sperry fire control system as described in the French patent No. 809,548.

Two listening posts X and Y (on a base of several kilometres) give the azimuth and elevation of the aircraft. These readings are transferred continuously to two small projectors (A and B) in the control apparatus and the intersection of the two light beams is found by raising or lowering a horizontal glass plate. A third projector C (corresponding to the A.A. gun) is then adjusted till its image on the glass plate coincides with the intersection of the beams A and B. By arranging so that A and B lie on the sides XC and YC of the triangle XYC, the elevation and azimuth of projector C is such that its line of prolongation would ultimately strike the aircraft spotted by the listening posts X and Y. In other words, the altitude of projector C gives the position of the gun for a straight line trajectory. The vertical adjustment of the glass plate corresponds to the height and the position of the spot on the plate gives the distance of the target. By following the motion of the spot of light it is easy to work out the speed and direction of displacement of the target and thus the usual gun corrections can be applied.

The advantage claimed for this method of fire control is the fact that no searchlights are required and the enemy will thus be subjected to A.A. fire without previous warning.

Several objections to this scheme naturally arise:—

(1) Errors in the original acoustic bearings.
(2) Size of apparatus (at least $2 \times 2 \times 1$ m.).
(3) In the case of an attack of several aircraft the acoustic detectors might not both be aimed at the same target.

High Explosive Shell (Artillery). (R. Meyer, Z.V.D.I., Vol. 82, No. 30, 23/7/38, pp. 879-883.) (58/10 Germany.)

After reviewing various types of shells, the author deals more explicitly with the fragmentation shell employed against ground personnel. On detonation, the casing of this type of shell breaks up into a large number of pieces which are projected over an egg-shaped area surrounding the point of impact. In order to achieve this object, careful attention must be given to the design and material employed. The steel must not be too tough, so as to avoid large splinters. On

the other hand, the casing must be strong enough not to burst in the gun. Addition of phosphorus (up to 0.1 per cent.) has been found beneficial and a properly designed 4-inch shell will produce on detonation at least 400 splinters weighing each at least 5 gm.

Safety in handling and the possibility of simple accurate mass production are the essentials of shell design. The usual process is by drawing square blocks fitted with a central hole. The drawing process has the advantage that the quality of the shell casing can be controlled. If suitable presses are not available, the ordinary machining processes may be employed.

Lately shell bodies made of cast steel have received attention. Although this construction is heavier and has thus to operate with a reduced filling of explosive, the splinter action of the cast steel is very good.

Principle and Test of the Mirror Type Pitot. (A. Klemin, J. Aeron. Sci., Vol. 5, No. 8, June, 1938, pp. 321-4.) (58/11 U.S.A.)

A considerable amount of experimental work, both in the wind tunnel and in full flight, has been carried out on the best location in which to place a pitot tube so that its readings may be correct at varying angles of attack in spite of wing interference. The literature of the subject is extensive and no entirely satisfactory position has been found even for the unflapped wing.

It occurred to the author that a pitot which would indicate correctly through a wide range of speeds, with approximate independence of its location, and independently of flap depression, might perhaps be achieved by placing the pitot in proximity to a small auxiliary aerofoil which would counteract the aerodynamic effects of the main wing. To this device the name mirror type pitot was applied, and the article gives a number of test results with this instrument.

It appears that the device, although not practicable as a service instrument on account of the size and aspect ratio of the mirror, will, nevertheless, prove useful in research and performance testing.

A Note on Some Accelerated Boundary Layer Velocity Profiles. (R. H. Mills, J. Aeron. Sci., Vol. 5, No. 8, June, 1938, pp. 325-7.) (58/12 U.S.A.)

The present paper deals with the two dimensional equations for the steady flow of a slightly viscous fluid over a flat plate.

The velocity profiles are assumed to be similar for all values of the abscissa x; and writing the velocities within the boundary layer as functions of $(Ry/Rx^{(p+1)/2})$, a separation of variables occurs for all flows whose velocity far from the surface of the plate, U, varies as A/x^p.

The velocity profiles are calculated for the case $p=1/3$.

An asymptotic expression for the velocity profiles, with p arbitrary, is given. This expression indicates that the velocity profiles are of the type that would occur if the boundary layer were accelerated by injecting additional fluid into the flow.

An expression for the variation of the local coefficient of skin friction with Reynolds number is also given, that is $C_f=2\,aR_x^{(p-1)/2}$.

Ship Stresses in Rough Water in the Light of Investigations Made upon the Motor Ship "San Francisco." (G. Schnadel, North East Coast Institution of Engineers and Shipbuilders, Transactions, Vol. 54 (Excerpt).) (58/13 Germany.)

The paper is of interest to the designer of flying boats since it gives for the first time correlative experiments on the shape of water waves, the impact forces on the hull, and the stresses set up in the ship structure.

Two methods were employed for the measurement of the waves:—

1. Photographic study with the Zeiss stereo camera.
2. A direct method by means of electric contact devices distributed over the hull.

The first method necessarily gives the shape and dimensions of the wave in the undisturbed water at some distance from the ship. In the second method, the water closes an electrical current which lights up a lamp. The various lamps are photographed on a rotating film and in this way the wave shape is reconstructed.

The forces on the hull are measured by the deflection of a certain number of diaphragms, the records being obtained by the well known D.V.L. scratch method. A similar method of recording is used for the internal strain gauges distributed over the structure of the ship.

It appears that the stresses in the ship are considerably affected by oscillation and impact (pounding). The author's measurements are mutually consistent and the importance of the work is recognised in the extensive discussion which concludes the article.

Pressure Losses for Fluid Flow in 90° Pipe Bends. (K. H. Beij, Bur. Stan. J. Res., Vol. 21, No. 1, July, 1938, pp. 1-18.) (58/14 U.S.A.)

Pressure losses were determined for nine 4-inch steel 90° pipe bends of radii from 6 to 80 inches. The results are discussed in relation to those found by previous investigators under comparable test conditions. For bends having radii of four pipe diameters or less, all the results which are discussed may be correlated on the basis of pipe roughness. Further data are needed to establish a working formula. No correlation could be obtained for the bends of larger radii. For such bends the maximum published values should be used in engineering work until more comprehensive data become available.

Theory of Two-Dimensional Potential Flow Round an Arbitrary Aerofoil. (H. Gebelein, Ing.-Arch., Vol. 9, No. 3, June, 1938, pp. 214/240.) (58/15 Germany.)

Three general theories concerning the potential flow round an aerofoil of arbitrary shape are discussed:—

(1) Method of conformal representation as laid down by Theodorsen and Garrick (N.A.C.A. Report No. 452).

(2) Generalisation of Birnbaum's theory for profiles of medium thickness (Z.A.M.M., Vol. 3, 1923, pp. 290, etc.).

(3) General investigation of the complex velocity function, making use of the relations first discussed by Weinig (Z.A.M.M., Vol. 9, 1929, p. 507; W.R.H., Vol. 14, 1933, p. 131; L.F.F., Vol. 12, 1935, p. 221).

Birnbaum's original theory (2) referred to infinitely thin wings which could be replaced by a vortex sheet. This method presents many advantages and several attempts have been made to extend it to profiles of medium thickness, so far without success.

Theodorsen's original method in the limit when applied to infinitely thin profiles does not lead to the same system of equations as the theory of the lifting vortex surface and thus cannot be considered as a generalisation of Birnbaum's work.

The author develops a new approximate theory which overcomes this difficulty.

The relative merits of the methods discussed will be exemplified by a worked out example which will appear in a subsequent issue of Ing. Arch.

Heinkel Explosive Rivets. (Flugsport, Vol. 30, No. 5, 2/3/38, pp. 110-112.) (58/16 Germany.)

The shaft of the rivet is hollowed out and filled with a special explosive detonating at 130°C. This explosive is stable, non-poisonous and leaves no corrosive residue after firing.

No cap is fitted over the tubular end of the rivet and after inserting in the hole to be riveted, the charge is fired by pressing an electrically heated tool against

the head of the rivet. The heat travels down the shaft and the explosion takes place after 1-5 seconds, depending on size of rivet. The explosion is entirely local and forces out the tubular shaft thus holding the rivet.

The following advantages are claimed:—

(1) No assistant holding the rivet is required.

(2) No counter weight is required and riveting can therefore be carried out in localities of difficult access.

(3) The rivet is tight (85 per cent. of strength of normal rivet) and can be used for tanks and floats.

(4) The method is suited for all shapes and sizes of rivets in any material, provided the latter has an extension of at least 15 per cent. Steel rivets can be used.

(5) The explosive rivet is specially suited for repair work under conditions where time available is short and lack of facilities exist.

Effect of Propeller Slipstream on Wings and Tail Surfaces. (J. Stuper, L.F.F., Vol. 15, No. 4, 6/4/38, pp. 181-205. Available as Translation No. 674.) (58/17 Germany.)

The experiments were carried out on a wing of 80 cm. span and 20 cm. chord, the effect of the slipstream being investigated both as regards change in lift distribution of the wing and changes in speed and direction of inflow at the tail surfaces. For the preliminary work, the slipstream (20 cm. diameter) possessed no rotary component and the results show that the increase in lift is appreciably less than that predicted by the theory of Koning, the local effects depending appreciably on the angle of incidence. This may be partly due to boundary layer effects at the nozzle from which the slipstream issues or due to the finite wing span employed.

In the subsequent experiments the slipstream had a rotary component and it was noticed that the two halves into which the slipstream separates on striking the wing do not reunite behind the wing, but retain a lateral displacement in the direction of rotation. Measurements of lift distribution and moment were also made for the case when the propeller axis makes an angle with the wing chord. The separation of the flow at the wing is affected by the propeller slipstream, the region where the jet contour leaves the wing being specially sensitive. The presence of the rotary jet also causes large differences in the individual contribution of the various elements of the tail surface to the total tail moment.

Recent Research on the Improvement of the Aerodynamic Characteristics of Aircraft. (E. F. Relf, J. Roy. Aeron. Soc., Vol. 42, No. 330, June, 1938, pp. 513-535.) (58/18 Great Britain.)

Aircraft characteristics may be broadly classified into two groups: Those concerned with performance and those concerned with stability and control. In other words, improvements in economy and in safety cover practically the whole of present-day research.

As regards economy or performance, it is now generally recognised that skin friction sets a lower limit to the drag of high speed aircraft. If the point of transition is known (*i.e.*, the relative proportion of laminar and turbulent boundary layer), the skin friction drag can be calculated with fair accuracy provided the surface is sufficiently smooth. Present-day machines already approach within reasonable distance of this ideal and there is every hope that design will ultimately triumph over the admittedly great practical difficulties of providing aerodynamic smooth surfaces for the whole of the aircraft. As regards control or safety much more remains to be done and among the numerous problems the author singles out two: Lateral stability near the stall and the problem of wing flutter.

Lack of lateral stability near the stall results in " wing dropping " which is due to an asymmetric stalling of the wing tips.

It appears possible to cure this by adopting a suitable profile for the tips, but full scale tests have so far not been carried out.

Turning now to the flutter problem, the author expresses the fear that with further increase in speed the present design precautions may not be sufficient to prevent a recurrence of this trouble. For this reason the technique of flutter measurements has been improved and new methods for tackling the mathematics are being developed.

Interference and Interaction from the Designer's Point of View. (M. Watter, J. Aeron. Sci., Vol. 5, No. 8, June, 1938, pp. 300-7.) (58/19 U.S.A.)

This paper treats certain phases of the turbulence problem generally defined as interference. Means of suppressing or minimising interference are proposed and the geometry of design is analysed in the light of the effect of interference phenomena. The results of a few wind tunnel tests made in connection with this study are presented in order to show satisfactory experimental verification of the methods suggested, which cover such a wide range of problems, including wing, nacelle and fuselage shadows, fairings and stability. Fourteen references.

A Study of Available Flap Data. (R. C. Molloy, J. Aeron. Sci., Vol. 5, No. 8, June, 1938, pp. 308-12.) (58/20 U.S.A.)

An analysis of published data on flaps indicates that in spite of the number of tests made, the results of such tests are by no means complete or consistent. These inconsistencies can probably be charged to slight changes in flap design for the same type of flap, to differences in testing technique, and to the effects of scale and turbulence. In the case of $C_{L\max}$ for split flaps, and for other types also, this characteristic changes with aerofoil thickness, camber, and camber position, in addition to changing with the factors already mentioned.

More accurate comparative test data are needed to settle the question of the superiority of one type of flap over another. More data on slotted flaps would be particularly useful.

Characteristics other than $C_{L\max}$ should be investigated more fully, in order that the designer may weigh those factors which are important in the choice of a type of flap to aid in take-off, as well as in landing. The effects of wing design variables on the aerodynamic characteristics of the wing flap combinations need further investigation.

Special Problems Connected with the Take-off and Landing of Aircraft. (J. J. Green, J. Aeron. Sci., Vol. 5, No. 8, June, 1938, pp. 313-20.) (58/21 U.S.A.)

A theoretical analysis has been made of the effect of gradient, wind, and combinations thereof, on the take-off and landing of aeroplanes. Formulæ and charts are given which permit the determination of the length of the ground run for any given conditions providing that the performance on a level surface in still air is known.

From American experiments it appears that

$$\text{(take-off run against wind)}/\text{(take-off run in still air)} = (1 - v/V)^{1.8}$$

where v = velocity of wind.

V = take-off speed of aircraft.

A similar relationship holds for the take-off of seaplanes in the absence of current, except that the index is 2 instead of 1.8. The effect of wind alone is to alter the length of run rather than the time of take-off. The effect of current alone is to alter the time of take-off without having much effect on the length of run. The take-off of a seaplane is thus always shortest if it takes place against the wind, irrespective of current direction.

(See also J. J. Green, Can. J. Res., Vol. 16, 1938, Sect. A, pp. 1-16.)

Propeller Problems Imposed by Substratosphere Flight. (C. F. Baker, J.S.A.E., Vol. 42, No. 7, July, 1938, pp. 285-8.) (58/22 U.S.A.)

This paper points out that high power sub-stratosphere flight will require a close co-ordination of aeroplane, engine, and propeller designers in order to ensure the most efficient conversion of power. If this co-ordination is not done, substantial penalties in propeller performance will be obtained.

Sub-stratosphere flight with high powers will require propellers which are appreciably heavier that present ones. However, although weights will increase, it is expected that the upward trend in specific weights can be reduced.

The Transition Phase in the Take-off of an Aeroplane. (J. W. Wetmore, N.A.C.A. Report No. 628, 1938.) (58/23 U.S.A.)

An investigation was undertaken to determine the character and importance of the transition phase between the ground run and the steady climb in the take-off of an aeroplane. The information was obtained from a series of step by step integrations defining the motion of a Verville A.T. biplane (weight app. 2,000lb.) during actual take-off. Both normal and zoom take-off were considered. During the former, the pilot left the ground at speeds ranging from 3 to 15 miles per hour in excess of minimum level flying speed and to climb at the same speeds. During the " zoom " take-off, the speed at the instant of take-off is the same as before, but is reduced to practically minimum flying speed during the climb. For normal take-off, the best transition is realised at the lowest possible take-off speed. Zoom take-off is only of advantage if the machine is heavily loaded and has to clear a high obstacle (100ft.).

The error in the calculation of air-borne distance of take-off by neglecting the transition phase varies from +4 per cent. (heavy load) to −4 per cent. (light load) for normal take-off. For zoom take-off the error is considerably greater.

The ground effect reduces the air-borne distance to attain a height of 100 feet by 5 per cent. (light load) and 8 per cent. (heavy load) respectively.

The Icing Problem on Aircraft. (A. Mirlés, Pub. Sci. et Tech. du Ministere de l'Air, B.S.T., No. 78, April, 1938.) (58/24 France.)

In order to study the problem of icing, an experimental station was established at the summit of the Puy de Dome (1,460 m.).

In this locality a wind of the order of 40 m./sec. is quite frequent and the high moisture content of the air together with the low winter temperature enable the formation of ice deposits to be studied under natural conditions. Certain experiments were also carried out in the propeller slipstream of an aero engine mounted in the open. After discussing the meteorological conditions favouring ice formation, experiments on the icing up of bodies of various shapes are described. As is well known, the deposits concentrate on wires and sharp edges and gradually build up in the direction facing the wind. In the case of aerofoils the leading edge is most subject to attack. Certain methods of de-icing depending on supplying heat electrically to the danger zones are described and it is pointed out that, once the ice has formed, much more energy has to be supplied for its removal than is required to prevent a deposit from forming. This shows the importance of an adequate warning device which has been developed by the author by placing a wire mesh over the intake of a venturi. By comparing the readings of two such instruments, one with and the other without a grid, an accurate warning of the possibility of ice formation is given before any marked deposits occur on the wings.

In addition to some good photographs, the article also contains an interesting summary of icing troubles experienced by civil aviation pilots.

Income and Subsidies of Various European Air Lines. (L'Aerophile, Vol. 46, No. 7, July, 1938, p. 163.) (58/25 ——.)

Company.	Year.	Subsidy.	Total Receipts, including Subsidy.	Subsidy, % Total.
Imperial Airways...	1934	£543,694	£1,197,809	45·4%
,, ,, ...	1935	£561,556	£1,425,167	39·4%
,, ,, ...	1936	£426,595	£1,539,065	27·7%
,, ,, ...	1937	£381,767	£1,604,061	23·8%
Air France ...	1934	Frs. 163,405,167 (£1,315,555)	Frs. 219,390,442 (£1,766,286)	74·48%
,, ...	1935	Frs. 161,553,925 (£1,300,619)	Frs. 220,385,737 (£1,774,305)	73·31%
,, ...	1936	Frs. 154,865,873 (£1,246,807)	Frs. 235,952,747 (£1,899,626)	65.63%
Deutsche Lufthansa	1934	Rm. 20,649,903 (£1,010,764)	Rm. 40,542,988 (£1,766,286)	50.93%
,, ,,	1935	Rm. 19,656,115 (£962,120)	Rm. 45,525,259 (£2,228,333)	43·18%
,, ,,	1936	Rm. 21,212,643 (£1,038,308)	Rm. 50,050,082 (£2,449,833)	42.38%
Sabena	1935	Frs. 12,605,499 (£72,031)	Frs. 35,026,450 (£200,151)	35.99%
,, ...	1936	Frs. 14,428,232 (£82,447)	Frs. 42,022,408 (£240,129)	34·33%
Ala Littoria ...	1934-1935	Lire 49,696,300 (£537,478)	Lire 55,822,011 (£603,742)	89.02%
,, ...	1935-1936	Lire 65,983,140 (£713,640)	Lire 97,327,982 (£1,052,650)	67.79%
K.L.M.	1934	Fl. 367,662 (£40,851)	Fl. 5,832,357 (£648,040)	6.3%
,, ...	1935	Fl. 548,000 (£60,888)	Fl. 6,653,706 (£748,189)	8.14%
,, ...	1936	Fl. 526,653 (£58,517)	Fl. 7,317,568 (£813,063)	7.19%
,, ...	1937	Fl. 548,000 (£60,888)	Fl. 9,248,000 (£1,027,800)	5·93%

Simplified Propeller Calculations. (I. H. Driggs, J. Aeron. Sci., Vol. 5, No. 9, July, 1938, pp. 337-344.) (58/26 U.S.A.)

The method of equivalent wing polars first suggested by Doepp (L.F.F., Vol. 13, No. 2, pp. 46-56) is very useful for determining the best propeller to fit any aeroplane design conditions. In its original form, however, no account is taken of the Goldstein blade interference factor (R. and M., No. 1674) and this may introduce appreciable errors in the induced power losses at high lift values for the blades.

The author has applied the necessary corrections, but comparison with experiment is rendered difficult by the absence of suitable model experiments. It appears that propeller tests run under any conditions other than those to be used in flight may lead to erroneous results and further work is urgently required. The author's formulæ lead to the following main conclusions:—

(1) The power lost in the slipstream is a fixed quantity and need not be considered when comparing various propeller designs.

(2) The static thrust per unit power increases with a decrease in tip speed.

(3) The tip speed for greatest efficiency is equal to the velocity of advance in the same units.

Formulæ for the Performance of Spark Ignition Engines at Altitude. (L. Auer, Z.V.D.I., Vol. 82, No. 27, 2/7/38, pp. 789-793.) (58/27 Germany.)

A number of formulæ are available by means of which the performance of an aircraft engine at altitude can be calculated provided the power output under a set of standard conditions is known. These formulæ are empirical and based on such test figures under altitude conditions as are available. Since power measurement at altitude is very difficult and only very few test benches reproducing altitude conditions on the ground are available, the formulæ in use at the present time cannot lay any claim to great accuracy. They are, however, useful in forming a basis of comparison. Unfortunately, the responsible authorities in different countries have so far not yet agreed on an international method of representation and the aircraft engineer is thus confronted by various formulæ (American, French, English and Russian) which all lead to different numerical results. These formulæ are defined by the author and their application to unsupercharged and supercharged engines is explained.

The subject requires more elucidation by actual measurements in flight.

Propeller Factors Tending to Limit Aircraft Engine Powers. (G. T. Lampton, J.S.A.E., Vol. 42, No. 7, July, 1938, pp. 289-92.) (58/28 U.S.A.)

There is a strong trend towards increasing aeroplane gross weights inasmuch as larger sizes simultaneously result in structural economy and aerodynamic improvement. The concurrent demand for larger power plants may be limited by the propeller since, at constant tip speed and velocity, its weight is proportional to the 3/2 power of the horse-power.

By assuming a specific engine weight curve for increasing powers and adding the propeller weight, specific weight curves for the power plant group are obtained. These curves show minima in the vicinity of 2,500 and 6,000 h.p. for 250 and 450 m.h.p. design speeds, respectively, at sea level. Multi-blade propellers and very high design speeds tend to reduce the weight penalty, and the author concludes that the ultimate limit to engine power is not yet in sight.

Aerodynamic Considerations Affecting Propellers for Large Engines. (G. W. Brady, J.S.A.E., Vol. 42, No. 7, July, 1938, pp. 293-300.) (58/29 U.S.A.)

From the aerodynamic standpoint, propellers for engines of several times present powers will operate just as efficiently as those for smaller powers. For long-range aircraft operating at altitudes of 20,000 to 30,000ft., three-blade propellers increased somewhat in diameter over what in current practice are definitely indicated although, for medium range types, the diameters of present practice scaled up by the square root of the take-off power ratio appear satisfactory.

As alternatives to the increased diameters for the long range high altitude aircraft, the three-blade propeller of about 15 per cent. small diameter with a two-speed reduction gear will give equal range but a poorer take-off, or the four-blade propeller of the same diameter as the smaller three-blade design will give almost equal range without a two-speed reduction gear and slightly poorer take-off.

The importance of pitch distribution designed for operating speeds is indicated, as is the necessity for keeping blade shank sections faired when exposed to the airstream, particularly in liquid-cooled installations. Propellers which can be feathered in case of power plant failures are considered essential to long range aircraft from the standpoint of safety and increased performance on the remaining engines.

Electric Testing Installations for the Development of Aero Engines. (E. Lotterle, Metropolitan Vickers Tech. News Bulletin, No. 619, 15/7/38, p. 8. E.T.Z., 7/7/38, pp. 709-14.) (58/30 Germany.)

The author describes examples of the application of electrical engineering in testing installations used in the development of aero engines. He deals in par-

ticular with testing installations for single cylinder engines, and for engines intended for high altitudes, for superchargers and for aero engine accessories. In conclusion, he briefly discusses electric converter stations for the larger testing installations. Illustrated with four diagrams and two photographs.

Principles Involved in the Cooling of a Finned and Baffled Cylinder. (M. J. Brevoort, N.A.C.A. Tech. Note No. 655, June, 1938.) (58/31 U.S.A.)

The author points out that the fin passage baffle of an air-cooled engine cylinder corresponds to a number of pipes in parallel. Assuming the wall temperature constant, the total heat transfer to the air entering the pipe at a given temperature can be calculated in terms of the dimensions of the pipe, the heat transfer coefficient, the mean speed through the pipe and the physical constants of the air. Since the heat transfer coefficient is known in terms of velocity and pipe dimensions whilst the velocity itself can be expressed in terms of pressure drop over the length of pipe, the total heat transfer can be expressed in terms of pressure drop, temperature difference of inlet air and pipe dimensions. Plotting these relations, the author shows that for fixed values of the pressure drop and temperature difference (air intake/wall) the heat transfer per unit intake area reaches a maximum for a certain l/d ratio (l = length of passage, d = hydraulic diameter). Moreover, at this optimum value of l/d, the heat transfer per unit frontal area is practically the same for any value of d. In other words, the " optimum " fin spacing mentioned in some previous researches is entirely due to the air passage having been of constant length in these experiments. Equivalent results can be obtained with other fin spacings if the baffle length is adjusted accordingly.

Buchi Turbo Charging. (Metropolitan Vickers Tech. News Bulletin, No. 620, 22/7/38, p. 7. Oil Engine, July, 1938, pp. 72-3.) (58/32 ——.)

This article gives data on the exhaust gas turbo charging method of pressure charging obtained from recent tests of a number of engines of widely differing types fitted with equipment of Buchi design. The results show the modern standards of performance attained with this system. Illustrated with one photograph and two diagrams.

Catalytic Combustion of Gases on Metals. (W. Davies, Engineering, 27/5/38, pp. 587-9. Eng. Absts., Vol. 1, No. 5, Section 3, June, 1938, p. 49.) (58/33 Great Britain.)

Pt and Ni wires 0.001in. in diameter were stretched within a cast iron cylinder one cubic foot in capacity, connected to vacuum pump, gas cylinders and gauge, the voltages across an ammeter shunt and rheostat being measured. Temperature was calculated from resistance, and rate of combustion by plotting temperature against power input. Results are given for air containing small percentages of H_2, CO and methane. With 1 per cent. H_2, reaction began very sharply at 200°C. With CO, combustion does not begin till about 400°C. For CO and H_2 rates of combustion at first increase and then decrease, the curves being parabolic about 1,200°C. The possibility of heating fine wires in an explosive mixture to above its ignition point is probably due to the intense thermal gradient—100°C. or more in a distance equal to the mean free path. In small amounts methane does not react below a wire temperature of 800°C. A small percentage of acetylene suppressed combustion of hydrogen, *e.g.*, 1 per cent. acetylene raised the explosion temperature of a 30 : 70 H_2 : air mixture from 280° to 600°C. The results agree well with recent theories of catalysis.

The Two-Stage Auto-Ignition of Hydrocarbons and " Knock." (G. P. Kane, Proc. Roy. Soc., Series A, Vol. 167, No. 928, 7/7/38, pp. 62-80.) (58/34 Great Britain.)

Previous investigations into the spontaneous ignition under pressure of the higher paraffins and olefins containing more than three carbon atoms have shown

that in the temperature range between ca. 270 and 400°C., ignition occurs by a two-stage process preceded by an induction lag t_1 before the formation of a cool flame and a second lag t_2 before the subsequent ignition of the cool flame products; increasing pressure shortens both these lags, and although kinetic relationships have been developed it has not been possible adequately to test them hitherto, owing to the extreme violence of the ignitions at pressures much above the minimum ignition pressure.

An optical recording manometer is described whereby it has been possible to measure t_1 and t_2 at pressures up to 15 atm. with an accuracy of 1/100 sec.

With propane t_2 decreases more rapidly than t_1 with increasing initial pressure, and at a critical pressure (about 8 atm.) the two-stage is replaced by a single stage process; the induction lag then decreases very rapidly with pressure. With propylene, where the induction lags are much greater, no such transition had occurred at pressures up to 12 atm.

The bearing of these results, both on the nature of the kinetic processes operative and on the problem of " knock," is briefly discussed, the latter phenomenon being attributed to the propagation of an explosion flame through a fuel air mixture in a state of enhanced chemical activity.

Limit of Detonation of Mixtures of Hydrocarbons with Air. (V. M. Rifin and A. Sovolik, Fuel, Vol. 17, No. 7, July, 1938, p. 224.) (58/35 U.S.S.R.)

The purpose of the experiments discussed in this paper was to study the formation of the detonation wave as regards its bearing on the phenomenon of pinking in internal combustion engines. The two problems of chief interest were: (1) The ability of hydrocarbon air mixtures to produce the explosive wave spontaneously; and (2) to sustain the propagation of a shock wave initiated from an external source. Experiments in a 30 m. long tube showed that a spontaneous production of the explosion wave was impossible in the mixtures of ethyl ether, of pentane, and of fractions of petroleum ether (35 to 39 deg.), with air at normal pressure and temperature, and ignition by a discharge from a high power condenser. In every case extinction was observed at a distance of less than 10 m. from the spark. For hydrocarbon air mixtures corresponding to the actual mixture in a petrol engine, the propagation of the explosion wave is possible only within the narrow limits of concentrations approximating to the stoichiometrical one. The same hydrocarbon air mixtures, containing 4 to 5 per cent. of CO_2—hence more similar to the actual mixture in an engine—are not capable of detonation. This is considered as proving that detonation in an engine is governed entirely by " chemical sensitisation " of the mixture during compression.

Diesel Deposits as Influenced by Fuels and Operating Conditions. (J. R. MacGregor and W. V. Hanley, J.S.A.E., Vol. 42, No. 7, July, 1938, pp. 272-80.) (58/36 U.S.A.)

Fuel deposition and ring sticking tests are described which were performed on several single cylinder and multi-cylinder service Diesel engines in the laboratory.

The development of an accelerated test method is outlined with special reference to the effects of engine variables on deposition. Decrease in load, speed, or jacket temperature or increase in altitude were found to increase fuel deposition. Increase in running time increases the exhaust deposits linearly but, within the combustion chamber, equilibrium deposition was reached in a few hours of operation.

Marked differences were found among fuels in the single cylinder test engine after 24 hours of operation under the accelerated conditions. Fuels doped with different types of cetane number improvers indicated that ignition quality is a factor in fuel deposition under certain operating conditions in some engines.

The results of the tests in one of the single cylinder engines were compared with the results obtained in the other engines. Although they correlate closely with the relative fuel deposition in certain of these engines, they were not indica-

tive of the results obtained in other engines which are relatively insensitive to fuel differences.

The tests demonstrated that the engine designer has much greater control over the quantity of fuel deposits formed than has either the fuel refiner or the engine operator.

Chemical Structure and Viscosity Characteristics of Lubricating Oils. (B. Yamaguchi, Aer. Res. Inst., Tokio, Report No. 162, April, 1938.) (58/37 Japan.)

As a continuation of the writer's previous paper, the present work contains the results of studies on the relation between the chemical structure and the viscosity association of high molecular weight hydrocarbons, such as those present in lubricating oil fractions. An equation expressing the relation in lubricating oils between viscosity association and viscosity temperature coefficient has been established, and, in order to study their viscosity association in relation to their chemical structure, calculations of viscosity association have been made with the aid of the equation for a number of high molecular weight hydrocarbons whose viscosity temperature coefficients and chemical structure are known. Finally, interesting conclusions have been drawn for these hydrocarbons in connection with the effect of chemical structure on the viscosity temperature coefficient.

Aircraft Fuels of High Octane Rate. (W. H. Hubner and G. Egloff, Oil and Jes. Journal, Vol. 36, No. 46, 31/3/38, pp. 103-112.) (58/38 U.S.A.)

The following table shows the rapid increase in the use of high octane fuels in the U.S.A. :—

Rating.	Per cent. distribution of U.S. Army Air Corps fuel requirements for the years—						
	1938	1937	1936	1935	1934	1933	1932
100	90	29	14	2	—	—	—
92	7	68	83	95	96	53	—
87	—	—	—	—	—	40	—
58-65	3	3	3	3	4	7	14

At the present time the total annual consumption of aircraft fuel in the U.S.A. is roughly 100×10^6 gallons, 40 per cent. of which is for military use. There has also been an increase in the octane rating of civil aircraft fuel from an octane number 83 in 1935 to 89 at the present moment. The author discusses the composition of such high grade fuels and describes the test methods employed for determining the octane rating. At the present moment there exists unfortunately three different test methods the results differing appreciably according to the technique adopted, especially in the higher range of rating. Extensive standardisation tests are, however, in progress at the moment both in the U.S.A. and in certain European countries with the object of determining a universal method for the octane range 87-100. In this connection it is also hoped that the fuel volatility requirements will be standardised. The large number of grade and specifications existing at the present moment are considered both troublesome and wasteful and every effort should be made to reduce their number to the minimum. It is suggested that the following four grades should cover all aircraft requirements :—Rating 73, unleaded; rating 80, 1 cc. tel./gallon; rating 90, 4 cc. tel./gallon; rating 100, 4 cc. tel./gallon.

Tests of a $7 \times 10\frac{1}{2}$-inch Bearing at 3,600 r.p.m (L. M. Tichvinsky, Trans. A.S.M.E., Vol. 60, No. 5, July, 1938, pp. 393-7.) (58/39 U.S.A.)

This paper deals with the first stage of the test of a $7 \times 10\frac{1}{2}$in. bearing at 3,600 r.p.m. of the journal.

It is shown that in gradually bringing such a bearing to full loading its performance as a guide bearing at zero and small loads changes to the performance of a power bearing at high loads. At small loads the losses are produced in the nearly uniform circumferential clearance, while at high loading the predominant

part of the losses is produced in the carrying oil film. The relative distribution of losses in the carrying oil film, reliefs, and upper clearance is represented graphically as a function of load and pressure on the basis of theoretical calculations.

Northerly Turning Error of the Magnetic Compass for Aircraft. (C. S. Draper, W. H. Cook and W. McKay, J. Aeron. Sci., Vol. 5, No. 9, July, 1938, pp. 345-354.) (58/40 U.S.A.)

Northerly turning error in the conventional magnetic compass is produced by accelerations during turns. The mechanism of these errors is completely described throughout the turn and a method is pointed out for minimising the effects in practice. This procedure involves the use of bank angles less than a critical value which varies with magnetic latitude. A mathematical study is made of improvements possible in compass performance by changing the dynamic coefficients of the instrument. The results show that (1) the error may theoretically be eliminated by using a sufficiently long undamped period of the card about the normal axis and (2) increases in damping forces cannot eliminate turning errors.

Stratosphere Balloon Altitude Comparison of Barometric and Photogrammetric Measurements. (W. G. Brombacher and M. R. Houseman, J. Aeron. Sci., Vol. 5, No. 9, July, 1938, pp. 355-9.) (58/41 U.S.A.)

Considering the 1934 flight results for 32 comparisons in the range from 42,000 to 62,000ft. above sea level, the average difference between the altitudes calculated by the barometric and photogrammetric methods was 0.7 per cent. without regard to sign. On the average the barometric altitude was 30ft. higher than the photogrammetric.

For the 1935 flight, for 60 comparisons in the range from 59,000 to 72,000ft. above sea level, the average difference was 0.36 per cent. without regard to sign and the barometric altitude was 93ft. lower on the average. The altitudes obtained by vertical angle measurement and the other two methods were also in satisfactory agreement.

Measurement of Engine Power in Flight. (O. W. Schey, J. Aeron. Sci., Vol. 5, No. 9, July, 1938, pp. 364-7.) (58/42 U.S.A.)

The N.A.C.A. has recently completed the development of a torque meter for measuring and recording engine torque during flight. The instrument operates on the hydraulic principle with photographic recording. Three specially designed diaphragms form part of the hydraulic system and are interposed between the propeller and the crankshaft so that the force between these two elements, when applied to the diaphragms, creates a pressure on the hydraulic system. A measuring diaphragm transmits the pressure to a moving film by means of a light beam and mirrors.

Considerable difficulty was experienced at first with failure of the torque cell diaphragm. This was traced to torsional vibration of the engine and overcome by fitting a dynamic balancer.

From the records obtained for fixed throttle operation between 0 and 15,000 feet, it appears that the b.h.p. as measured agreed within 2 per cent. with that predicted on the assumption that the engine power varied directly as the manifold pressure and inversely as the square root of the absolute temperature. The engine employed was an air-cooled radial of approximately 450 h.p. and tests with other types will be required before this agreement may be accepted as general.

Highest Frequency of Torsional Vibration. (G. G. McDonald, Engineer, 13/5/38, pp. 542-4. Eng. Absts., Vol. 1, No. 5, Section 3, June, 1938, p. 59.) (58/43 Great Britain.)

In certain very high speed systems destructive stresses may be set up through coincidence of one of the lower impulse harmonics and the highest frequency of

natural vibration. The author has devised a simple graphical method for locating nodes in an idealised system comprising a number of rigid mass moments of inertia spaced in any manner along an inertialess shaft of uniform torsional elasticity. A system with m masses gives $(m-1)$ nodes if " free-free," $m-$ if " fixed-free," and $(m+1)$ if " fixed-fixed." The conception is developed from a geometrical standpoint for a single mass " fixed-free," four mass " free-free," three mass " fixed-free " and six mass " free-free " systems, and it is explained how it can be applied to the case of axial vibrations of masses on a rod. In a further contribution (" The Engineer," 27th May, 1938, p. 592) the author discusses an analogous optical construction suggested by Dick (" The Engineer," 11th March, 1938, pp. 267-268).

On the Problem of Stress Distribution in Wide Flanged Box Beams. (E. Reissner, J. Aeron. Sci., Vol. 5, No. 8, June, 1938, pp. 295-9.) (58/44 U.S.A.)

The structural analysis of monocoque and semi-monocoque structures, such as stressed skin wings, presents a number of complicated questions. One of these has to do with the fact that in a hollow wide flanged box beam, as such a wing may be considered, the stress distribution deviates appreciably from that in an ordinary " beam " even when its walls are so stiff that no local instabilities occur in the skin.

This paper contains a contribution to this problem which is often called the problem of " shear lag." In Section I, some general statements concerning this problem of stress distribution are discussed, some of which have been made previously by different authors. In Section II a quantitative theory of the stress distribution in rectangular corrugated box beams is developed which is both simple and quite rigorous. It permits solving problems for corrugated beams, which, for beams consisting of flat sheets, are mathematically very complicated and have not so far been solved. In those cases where the analysis of the flat sheet beam is feasible, the corresponding problem for the corrugated beam admits of a much simpler solution.

Resistance Welding Plant for Stainless Steels. (Metropolitan Vickers Tech. News Bulletin, No. 620, 22/7/38, p. 6. Welding Industry, July, 1938, pp. 210-12.) (58/45 Great Britain.)

This description of a resistance welding installation recently completed by the Soudvre Electrique Languepin consists mostly of details of the Budd type control apparatus and the special types of tongs designed by Languepin. A device for warning the operator of an inadequate or an excessive value of the time current product is also described. The installation is intended for welding austenitic stainless work-hardening high resistance steels.

Illustrated with six photographs.

X-Ray as an Aid in the Manufacture of Aluminium Castings. (G. E. Stoll and A. T. Ruppe, Metropolitan Vickers Tech. News Bulletin, No. 620, 22/7/38, p. 6. Trans. American Soc. Metals, June, 1938, pp. 801-15.) (58/46 U.S.A.)

This paper deals with the application of radiography to the examination and control of foundry procedure. The effect of change in positions of risers, pinhole trouble, inspection and reduction of manufacturing costs are discussed in so far as they are affected by X-ray examinations. Finally the authors give some details of X-ray operation costs.

Illustrated with 12 photographs and one diagram.

Thermal Expansion and the Effect of Heat Treatment on the Growth Density and Structure of Some Heat Resisting Alloys. (P. Hidnert, Bur. Stan. J. Res., Vol. 20, No. 6, June, 1938, pp. 809-23.) (58/47 U.S.A.)

Coefficients of linear expansion for various temperature ranges between 20 and

1,000°C. were obtained on some new heat resisting alloys: An iron-chromium-aluminium alloy and three iron-chromium-aluminium-cobalt alloys. No polymorphic transition was observed in these alloys between 20 and 1,000°C. The alloys exhibited growth (0.82 to 2.81 per cent.) after various heat treatments at temperatures up to 1,400°C. Additional heat treatments would probably cause additional growth. The densities of the mechanically worked iron-chromium-aluminium alloy and iron-chromium-aluminium-cobalt alloys increased 1.12 to 2.50 per cent. as a result of various heat treatments to 1,400°C. Well marked grain growth occurred in the heat-resisting alloys as a result of various heat treatments at elevated temperatures.

Research on Materials and Modern Design. (A. Thum, Engineering, No. 3,785, 29/7/38, pp. 143-146.) (58/48 Germany.)

In certain classes of engineering, such as aeronautics, the weight of material making up the structure is of paramount importance.

It is now being realised that by a better understanding of fundamental principles, a considerable saving in weight is also possible for other types of engineering structures. Reduction in weight does not only lead to a direct reduction in cost, but the finished product may be definitely superior. Now a structure may be subjected to a variety of loads such as dead loads, fluctuating loads, starting impacts, applied deformation and non-uniform heating.

Even if the load is known, the resultant stresses in the structural elements can only be calculated for parts of relatively simple shape. The ultimate aim of the designer to utilise his material to the utmost at every point is thus very difficult to realise. Of great importance is the allowance for overload and this is intimately connected with the number of times such overloads are likely to occur during the normal life of the structure. The author shows how for certain materials, shapes and methods of stressing, overloads may be harmless and will not lead to a reduction in fatigue strength provided they do not occur too frequently. An interesting example of modern lines of development is furnished by the cast crankshaft. Here the better shape possible with casting more than makes up for the reduction in tensile strength of the material, the latter being only justified if a very much more expensive design is used.

Similarly, modern transmission shafts for motor cars are no longer made of extensively heat treated material, but instead a certain amount of plasticity is allowed so that under overload conditions, flow can take place over the whole length of the shaft.

Compression Struts with Non-Progressively Variable Moment of Inertia. (B. Radomski, L.F.F., Vol. 14, No. 9, 20/9/37, pp. 438-443. Available as Translation T.M. 861.) (58/49 U.S.A.)

The buckling failure conditions for a bar with non-progressively variable moment of inertia J_n, although constant over length l_n, are developed.

For two cases: (1) Bar consisting of two lengths l_1 and l_2 with J_1 and J_2; (2) bar consisting of three lengths l_1, l_2 and again l_1, with J_1, J_2 and again J_1 (symmetrical with respect to centre), graphs are plotted for different ratios $J_1 : J_2$ over $l_1 : l_2$, showing a mean moment of inertia J_m, with the aid of which the buckling strength P_k of the bar with sudden variations of the moment of inertia can be represented in the Euler form.

Load Tests on a Stiffened Circular Cylindrical Shell. (E. Schapitz and G. Krumling, L.F.F., Vol. 14, No. 12, 20/12/37, pp. 593-606. Available as Translation T.M. 864.) (58/50 U.S.A.)

For the purpose of checking and supplementing the theoretical computations carried out by the D.V.L. on the force distribution in cylindrical shells, tests are described whereby the stress distribution may be determined in a stiffened circular cylindrical shell loaded longitudinally at four symmetrically situated points. Of

particular importance are the cases investigated of groups of bending and arching or convexing forces, respectively. From the stress measurements on the longitudinal stiffeners, the shear stresses and the bulkhead ring stresses in the skin can be evaluated. These measurements showed that the " simple shear field " used in theoretical computations, in which all normal stresses in the skin are neglected, must be extended by the addition of the transverse or circumferential stresses (denoted by O_y) if the bulkhead rings are not riveted to the skin. The effect of buckling of the skin on the reduction of the stress disturbance within the load range investigated appeared to be slight. If the direct attachment to the skin of all of the bulkheads is loosened, the stress disturbance is reduced at a somewhat slower rate along the cylinder than is the case when the first two bulkheads are attached to the skin.

Investigation of Stress Conditions in a Full-Size Welded Branch Connection. (F. L. Everett, A. McCutchan, Trans. A.S.M.E., Vol. 60, No. 5, July, 1938, pp. 399-410.) (58/51 U.S.A.)

This paper presents the results of an investigation of stress conditions in an 8in. diam. 0.500in. wall test manifold having a full size welded branch connection. Stresses were determined from strain gauge measurements on the outer surface of the manifold at some 50 stations in the vicinity of the welded juncture of header and branch. High stresses were found to exist on the outer surface at the flat portion on the side of the manifold. No evidence of high stress was found on the outer surface of either the unreinforced or reinforced manifold in the vicinity of the crotch, although high stresses were deduced analytically as probably existing in the inside wall at this location in the unreinforced manifold.

It is concluded that the ring type of reinforcement described will develop the full strength of the pipe.

The Fatigue Strength of Hollow Crank Pins (Effect of Reinforced Oil Hole). (H. Cornelius and F. Bollenrath, Z.V.D.I., Vol. 82, No. 30, 23/7/38, p. 885.) (58/52 Germany.)

Two types of crank pins were experimented with. In the normal type, a cylindrical hole of constant diameter traverses the whole length of the pin, the oil passage to the connecting rod being in the form of a transverse hole in the wall. In the reinforced type, a ring of metal is left in the neighbourhood of the oil hole, the crank pin being bored out from the two ends separately. Experiments show that the fatigue strength under torsion is increased 26-33 per cent. by leaving the bridge of metal to reinforce the oil hole.

Using this type of pin, further experiments were carried out on the effect of double-duro hardening on the fatigue strength. In this process the metal is heated in an acetylene flame and then quenched in water.

The double-duro hardening generally led to a considerable reduction in the fatigue strength. Only if the original heat treatment was such as to produce a relatively soft pin did the acetylene hardening show a small beneficial effect.

Polar Diagrams for the Solution of Deflections of Axially Loaded Beams. (J. D. Akerman and B. C. Stephen, J. Aeron. Sci., Vol. 5, No. 9, July, 1938, pp. 360-3.) (58/53 U.S.A.)

Since polar moment diagrams give the shear, moment or solution for deflection at any point along the beam, the exact nature of stresses along the whole span is known and no approximations are involved. In the process of solving analytically a person is tempted to use assumed or average values.

Since it is a simple problem to draw a polar moment diagram using the exact moments of inertia, its use is recommended to avoid possible errors.

On the Influence of a Resonator upon the Field of Sound. (K. Sato and K. Kubo, Aer. Res. Inst., Tokio, Report No. 163, April, 1938.) (58/54 Japan.)

The ray of sound is projected on to a Helmholtz resonator and the sound field in its neighbourhood is investigated in detail.

When the resonator is out of tune, its presence causes a slight effect on the sound field. When the resonator is in action it absorbs the energy of sound from the surrounding field, a part being re-radiated as a spherical wave.

Luminous Enamels. (Z.V.D.I., Vol. 82, No. 30, 23/7/38, p. 884.) (58/55 Germany.)

Luminous enamels are now available which resemble ordinary enamels in that they are weather proof and can be cleaned like ordinary enamels. After previous exposure to light, they continue to glow in the dark for several hours.

The luminous enamels do not depend on radio-active substances, the phosphorescence being produced by the additions of a powdered zinc/sulphur/phosphorus compound to the ordinary paint prior to the normal stoving process (800°C.).

The luminous enamels are comparatively cheap and are receiving extensive application in anti-aircraft defence schemes (air raid shelters and sign posts).

Application of the Phase Integral Method to the Analysis of the Diffraction and Refraction of Wireless Waves Round the Earth. (T. L. Eckersley and G. Millington, Phil. Trans. Roy. Soc., Series A, Vol. 237, No. 778, 10/6/38, pp. 273-309.) (58/56 Great Britain.)

The phase integral theory leads to the complete form of the solution for points on the surface of the earth, and presents the analysis in a form which exhibits clearly the physical nature of the problem. In addition, it extends the solution to points above the surface of the earth, and to the case where air refraction is present as an important factor. While the solutions are not general in the sense of applying to any point in space, however far from the earth or near to the transmitter, they provide a complete basis for calculating all the cases of practical importance. In particular the theory has been applied to the preparation of a set of ground curves for various wave lengths from 2 to 2,000 m., and of a set of height-gain curves for the range 2-10 m. It has also provided the necessary material for calculating the probable effects of air refraction.

Brushes of Electric Machines. (P. Szereszewski, Metropolitan Vickers Tech. News Bulletin, No. 619, 15/7/38, p. 7. R.G.E., 9/7/38, pp. 35-42.) (58/57 France.)

The author reviews a number of recent articles concerning the operation of rubbing contacts used on the brushes and commutators of electrical machines. He considers the mechanism of the contact between brush and commutator, the voltage drop and finally the wear of brushes, rings and commutators. He investigates the influence of pressure, hygroscopic state and speed on this wear taking as a basis the results obtained by various investigators. Illustrated with seven diagrams.

Radio Direction Finding on Wave Lengths Between Six and Ten Metres. (R. L. Smith-Rose and H. G. Hopkins, J. Inst. Elec. Eng., Vol. 83, No. 499, 20/7/38, pp. 87-97.) (58/58 Great Britain.)

The authors describe the development of simple experimental direction finders for wave lengths between 6 and 10 metres, and their use in an investigation of the accuracy of direction finding on these wave lengths. It is shown that the inherent accuracy of the instruments is well within the limits of $\pm 2°$, while their sensitivity is sufficient for observation on an experimental 50 watt transmitter at

ranges up to 22 miles over flat ground. Bearings have also been taken on signals emanating from London television transmitters, blind landing beacons, and also from commercial and amateur transmitting stations some 3,000 miles away.

A brief study has been made of the behaviour of the loop direction finder when horizontally polarised waves are emitted at the transmitting station. It is shown that the errors experienced in this case can be almost entirely eliminated by the use of a rotating spaced vertical aerial arrangement in place of the loop. The evidence resulting from the use of this Adcock type of direction finder indicates that the errors with the loop set are due to the reception of horizontally polarised waves.

The Measurement of the Lateral Deviation of Radio Waves by Means of a Spaced Loop Direction Finder. (R. H. Barfield, J. Inst. Elec. Eng., Vol. 83, No. 499, 20/7/38, pp. 98-110.) (58/59 Great Britain.)

The paper gives an account of some systematic measurements of the lateral deviations of wireless waves received at Slough from various short wave transmitters over a period of several months. The measurements were made by means of a spaced aerial direction finder of the four fixed loop type, and the first part of the paper is devoted to a description of the apparatus, together with an account of its performance in respect of instrumental accuracy, pick-up factor, and other characteristics.

The results obtained show that the variations in bearings which arise from instrumental causes do not exceed about 2°, and are usually of the order of 1°. The records demonstrate that lateral deviation occurs for the above cases to an extent which depends on the range and type of the reflected waves observed. Deviations of 10° to 20° were recorded from the more distant stations, while in the case of Dorchester, distant 160 kilometres, the deviations were as much as 50° on occasions. From a study of these observations it is concluded that the effective points of reflection at the ionosphere may be as much as 50-100 km. out of the great circle path.

A Radio Control System for Model Aircraft. (L. A. Weiss, The Aero Modeller, Vol. III, No. 33, August, 1938, pp. 447-451.) (58/60 Great Britain.)

The aircraft receiver weighs about 6lbs. and is intended for a relatively large engine-driven model of 14ft. span.

The emitting station sends out a continuous train of 6 m. waves which can be modulated at will at seven different audio frequencies in the neighbourhood of 200 cycles per sec. The required modulation is produced by a vibrating reed and the receiving circuit is such that the corresponding reed possessing the modulation frequency is set in resonant vibration. This closes a relay circuit which in its turn operates a small electric motor to move the controls. The seven reeds provided suffice for the operation of the elevator (2), aileron (2), rudder (2) and ignition (1). Some details of the electrical circuits are given.

Flight tests have so far not been carried out.

Some Fundamental Factors in the Design of Permanent Magnets. (Post Office Engineering Dept., Library Circular, Vol. 15, No. 5, 1938, Informative Summary No. 19, pp. 1-6; Post Office Research Station, Dollis Hill, London, N.W.2.) (58/61 Great Britain.)

The simple requirements of magnet design are formulated and the significance of the quantities involved is discussed by consideration of the demagnetisation curve of a magnetic material. The pertinent properties of some alloys are given in the following table:—

Magnetic Property.	Alnico	Alni	35 % Cobalt Steel.	15 % Cobalt Steel.	3 % Cobalt Steel.	6 % Tungsten Steel.
Remanence ...	7,500	5,500	9,000	8,000	7,200	10,500
Coercive force ...	500	500	255	195	135	65
BH_{max}	18×10^5	12×10^5	10×10^5	6×10^5	4×10^5	3×10^5
H at BH_{max} ...	380	320	155	120	90	45
B at BH_{max} ...	4,700	3,800	6,000	5,100	4,500	7,100

In order that the flux density shall be reasonably high, the demagnetising force H_d must be appreciably less than the coercive force H_c. In the case of the older alloys, such as tungsten steel with a coercive force of 65 c.g.s. units, the maximum value of demagnetising field which can be allowed to develop without a serious reduction in flux density is limited to a fraction of this value. In the case of the newer alloys with coercive forces of 500, demagnetising fields of the order of ten times those allowable in tungsten steel can be developed without serious reduction of flux density, and in consequence very much shorter magnets of the newer materials can be used without serious demagnetisation.

A Direct Reading Radio Wave (Reflection Type) Absolute Altimeter for Aircraft. (S. Matsuo, Proc. Inst. Rad. Eng., Vol. 26, No. 7, July, 1938, pp. 848-858.) (58/62 Japan.)

A frequency modulated radio wave is emitted from the plane and the beat frequency resulting from the combination of direct and ground reflected wave is measured. This beat frequency depends directly on the altitude and can be recorded as such by a pointer reading.

The wave length employed was 50 cm. with a modulative frequency of 25 cycles/sec.

Ground calibration tests with this instrument are described for distances ranging from 4 to 160 m. (waves emitted horizontally and reflected from a vertical obstacle).

It appears that the accuracy is ample for navigational purposes, the power consumption being of the order of 2 watt.

No weights are given.

The Graphical Solution of Ordinary Differential Equations. (V. A. Bailey and J. M. Somerville, Phil. Mag., Vol. 26, No. 173, July, 1938, pp. 1-31.) (58/63 Great Britain.)

It is shown how a number of simple and inexpensive graphical devices may be applied to the solution of a large class of ordinary differential equations such as are frequently met with in applied mathematics. The relatively high cost of machines like Bush's differential analyser leaves room for such graphical methods when an accuracy of the order of 1 per cent. is sufficient. The treatment is general and emphasis is laid on the method of attack rather than on the solution of particular equations. In a subsequent paper, the application of these methods to particular equations of importance in various branches of applied mathematics will be given in greater detail.

On Bi-Partitional Functions. (P. V. Sukhatme, Phil. Trans. Roy. Soc., Series A, Vol. 237, No. 780, 10/6/38, pp. 375-409.) (58/64 Great Britain.)

The transformation formulæ of symmetric functions involve arithmetical functions, each of which depends from two partitions of the same partible number. Of these bi-partitional functions twelve may be recognised as fundamental. Some of these have been previously studied individually, and in the present paper an attempt is made to set out systematically their mutual relationships and, with respect to each, their connections with distributions in plano and with the combinatorial problems of which they afford solutions. Particular attention is given to the practical evaluation of these functions for the partitions of numbers up to about twenty, with a view to their use in the simplification of heavy algebraic transformations.

LIST OF SELECTED TRANSLATIONS.

NOTE.—Applications for the supply of copies of translations mentioned below should be addressed to the Under-Secretary of State, Air Ministry (R.T.P.), Kingsway, W.C.2, and will be dealt with as far as availability of stocks permit.

Suggestions concerning new translations will be considered in relation to general interest and facilities available.

TRANSLATION NO. AND AUTHOR.	TITLE AND JOURNAL.
	SUPERCHARGING.
517 v. der Null, W. ...	*The Design of Aero Engine Superchargers.* (Luftfahrtforschung, Vol. 14, No. 4-5, 20/4/37, pp. 244-53.)
517A	*Notes on Symbols Used in Translation No.* 517.
594 Précoul, M.	*On a Carburettor Problem Associated with the Supercharged Engine Operating at Altitude.* (L'Aerotechnique, No. 171, pp. 36-45—Supplement to L'Aeronautique, No. 214, March, 1937.)
627 Leist, K.	*Exhaust Driven Superchargers.* (Luftfahrtforschung, Vol. 14, No. 4-5, 1937, pp. 238-43.)
628 Schmidt, A. F. ...	*Thermodynamic Investigations on the Process of Turbo-Supercharging and Basic Experiments on an Exhaust Driven Supercharger.* (Luftfahrtforschung, Vol. 14, No. 4/5, 1937, pp. 233-7.)
	ENGINES.
509 Lindner, W. ...	*Experiments on the Scavenging Process of Two-Stroke Engines.* (V.D.I. Research Publication No. 363, pp. 9-22.)
586 Thum, A. ... ... Strohauer, R. ...	*Testing of Bearing Metals and of a Complete Bearing under Dynamic Load Conditions.* (Z.V.D.I., Vol. 81, No. 43, 23/10/37, pp. 1245-8.)
	AERODYNAMICS AND HYDRODYNAMICS.
520 Hoerner, S. ...	*Tests on the Wind Tunnel at the Technical High School, Brunswick.* (Luftfahrtforschung, Vol. 14, No. 1, 20/1/37, pp. 36-43.)
524 Dietze, F.	*Calculation of the Lift of a Vibrating Aileron.* (Luftfahrtforschung, Vol. 14, No. 7, 20/7/37, pp. 361-2.)
543 Weinig, F.	*On the Theory of the Under-Water Wing and of the Gliding Surface.* (Luftfahrtforschung, Vol. 14, No. 6, 20/6/37, pp. 314-24.)
563 Doetsch, H. ... Kramer, M.	*Systematic Profile Investigations in the Large Wind Tunnel of the D.V.L.* (Luftfahrtforschung, Vol. 14, No. 10, 20/10/37, pp. 480-5.)
631 Cicala, P.	*Experimental Investigations on the Aerodynamic Forces on an Oscillating Wing.* (L'Aerotecnica, No. 5, May, 1937, pp. 405-14.)

TRANSLATION NO. AND AUTHOR.	TITLE AND JOURNAL.
	INSTRUMENTS.
484 Danielzig, H. ...	*The Behaviour of Towed Static Pressure Recorders at High Speeds.* (Luftfahrtforschung, Vol. 14, No. 6, 20/6/37, pp. 304-9.)
	ELASTICITY.
610 Grammel, R. ... Klotter, K. ... Sanden K. Von ...	*The Elastic Deformation of Crankshafts during Torsional Oscillations.* (Ing.-Arch., Vol. 7, No. 6, December, 1936, pp. 439-65.)
	PROPELLER NOISE.
486 Ernsthausen, W. ...	*The Origin of the Noise of Airscrews.* (Luftfahrtforschung, Vol. 13, No. 12, 20/12/36, pp. 433-40.)
	ICING.
368 Pivetti, V.	*Flight in Clouds. Ice Formation.* (Rivista Aeronautica, Vol. 12, No. 2, Feb., 1936, p. 171.)
587 Faure, A. ... ... Rideau ... ... Ducret	*Methods of Overcoming Icing Trouble on Aircraft.* (Les Ailes, No. 839, 15/7/37, pp. 6-7.)
	ARMAMENT.
544 Vilser, W.	*Considerations Regarding the Penetration of Projectiles into Solid Bodies.* (Wehrtechn. Monatshefte, Vol. 40, Nos. 3 and 4, March and April, 1936, pp. 134-43 and 167-75.)
598 Brissot, C.	*Aerial Combat—Probability of Hitting Target as a Function of the Rate of Fire.* (Rev. de l'Arm. de l'Air, No. 100, Nov., 1937, pp. 1257-77.)
	AIRCRAFT.
506 Neesen, A. ... ... Teichmann, A. ...	*Remarks on the New Editions of the German Aircraft Strength Specifications (Dec., 1936).* (Luftwissen, Vol. 4, 1937, pp. 43-52.)
512 Reissner, H. ...	*New Problems in Static Stressing of Aircraft.* (Zeit fur Flugtechnik u. Motorluftschiffahrt, Vol. 18, No. 7, 14/4/27, pp. 153-8.)
605 Mewes, E.	*The Impact Forces on Seaplanes during Take-off and Landing.* (Vereinigung L.F.F. Jahrbuch, 1935, pp. 139-54.)

REVIEWS.

CAPTAIN TH. E. SOENNICHSEN: "DIE SEEMANNSCHAFT IN DER LUFTWAFFE" (Sailorship in the Air Force). Collection "Handbuecher der Luftwaffe." Berlin, 1938. Publ. by Verlag von E. S. Mittler & Son. 168 pp., 37 photos and tables, 150 figs. Price RM.2,80.

This booklet is a manual intended for the instruction of personnel serving with the naval wing of the German Air Force. It refers to everything connected with the handling and navigation of water craft in the service, including the special high-speed motor-boat classes required for seaplane stations. In the technical and nautical respect the author (formerly a captain of the merchant marine and at present a nautical instructor in the German Air Force) deserves full marks for the clear way in which the matter is dealt with. The manual is really comprehensive, instructive, full of practical experience and up to date. The towing and general handling of seaplanes on the water is included, as well as regulations, signals, first-aid advice, etc. A dictionary of special nautical terms is added. All definitions given are precise and yet easy to understand for novices to salt-water and wet aeronautics.

Dr.-Ing. KARL KLOTTER: "EINFUEHRUNG IN DIE TECHNISCHE SCHWINGUNGSLEHRE" (Introduction into the Theory of Engineering Oscillation Problems). Vol. 1, "Einfache Schwinger" (Simple Oscillating Systems). Berlin, 1938 206 pp., with 208 figs. Publ. by Verlag von Julius Springer. Price

This textbook is an introduction for engineering students and also for practical designers encountering oscillation problems and conversant with the elements of calculus. The author has endeavoured to pursue a strictly systematic sequence through the thorny regions of oscillations, vibrations and flutter.

The first volume begins with the general definition and deals with the kinetics of simple oscillating systems (*i.e.*, those with only one degree of free movement, like the pendulum), showing the application of the general theory to well-known engineering problems (metacentric oscillations of ships), including elastic systems (oscillations in simple structures, torsional oscillations, spring systems, etc). Beside the exact computation of periods by the "energy method," approximations with the help of Raleigh's method are given. A chapter dealing with special systems refers to the theory of certain instruments for vibrational research like the "Pallograph" of Schlick and Geiger's "Vibrograph." Final chapters deal with the theory and application for free and damped oscillations with linear characteristics, for aperiodics and pseudoharmonic systems, enforced oscillations (Foettinger's Torsional Indicator), etc.

A second, not yet published, volume will deal with systems with several degrees of free movement (technically the most important kind), and a third volume with systems with a complete freedom of movement (continuous systems).

British works on oscillation problems are frequently referred to.

FLIGHT HANDBOOK. A GUIDE TO AERONAUTICS.
W. O. Manning, F.R.Ae.S., and the Technical Staff of *Flight*. *Flight* Publishing Co., Ltd. 1938. 3s. 6d. net.

The object of this book is to give, in as simple terms as possible, an outline of the aerodynamics of aircraft and their construction, in order to encourage the reader to take a deeper interest in aviation and make a study of more advanced books.

Mr. Manning and the Technical Staff of *Flight* have, in the compass of only 140 pages, covered a wide range competently. The quart has been successfully compressed into the pint pot and the price of the pint is extremely reasonable for the excellent quality of the nourishment provided.

In Chapter I first principles are discussed, with a description of types of aircraft, from fast fighters to modern commercial flying boats, interspersed with comparisons of early aircraft and how the modern machine has improved upon them.

Chapter II deals with aerodynamics, the mechanism of lift, vortices, circulation, air flow generally, stalling, skin friction, drag, and so on, with the general effect of air flow under all conditions upon structural design. The difficulties of explanation have been excellently surmounted.

Chapter III is concerned with aircraft structures, and covers the field from wooden structures to stressed skin. It is very fully illustrated with a wide range of examples. Chapter IV covers gliders and sailplanes; Chapter V balloons and airships; and the final chapters on airscrews and instruments. The explanations, though short in many cases, are quite clear and sufficient for any reader to understand the fundamental principles involved.

For those who have no knowledge and wish to learn, and for those who have some knowledge and wish to learn more, this *Flight* Handbook is well worth while possessing.

J. Schnippenkoetter and Th. Weyres: "Physik der Luftfahrt" (Aeronautical Physics). Supplement 13 to "Physik fuer hoehere Lehranstalten" (Physics for High Schools). Berlin, 1937. Published by Ferd. Duemmlers Verlag, 119 pp. with 205 Figs. Price RM. 1.90.

This booklet forms part of supplementary additions attached to a German standard school book. In Germany, official regulations require aeronautics to be incorporated in the school instruction as far as possible. In air-minded Germany latest regulations go even further and demand that aeronautical matter has to form a basis of everybody's school instruction in physics, and that a fair part of the general science instruction has to be devoted to aeronautics. In order to comply with this modern conception generally (*i.e.*, apart from special aeronautical instruction courses introduced at all schools) the authors of a well known science class book for high schools have compiled this supplementary volume.

Its eight chapters deal with general classification and terminology of aircraft, with the characteristics of the atmosphere, with air resistance, with elementary mechanics of aircraft and airscrews, and with mechanical principles of engines. From the engineering point of view one might suggest that more care should be taken to accustom the pupil to the importance of dimensions to be introduced into formulæ used. Formulæ stated without dimensions are always objectionable and will be liable to cause confusion especially in a class book for physics where physical units and engineering units are necessarily mixed. The chapter dealing with the elements of meteorology deserves mentioning as very well written. The derivation of Bernouilli's fundamental law of hydrodynamics is very instructive.

A study of this inexpensive booklet can be recommended for all interested in aeronautical instruction.

G. Siegel: "Angewandte Lastannahmen Ueber Groesse und Angriff von Luftkraeften an Flugzeugen" (Applied Load Assumptions with Regard to Magnitude and Direction of Air Forces Acting on Aeroplanes). Berlin, 1938. Published by C. J. E. Volckmann Nachf. E. Wette. 175 pp. with 57 Figs. and nine separate form sheets. Price RM. 8.—.

Not so many years ago an aeroplane stress man was capable of calculating the load assumptions valid for a design within an hour or so's time. To-day it requires the tedious effort of a skilled aerodynamical scientist for several weeks to discover the approximate air loads supposed to be acting on aeroplane parts.

This book seems to be the first effort made to interpret the practical application

of the loading requirements for the stressing engineer. The author has obviously done his best to make his work an instructive and practical one, and several samples referring to modern aeroplanes are calculated *in extenso*. Unfortunately for the English reader, the book is entirely based upon German load assumptions (of December, 1936), and, therefore, the desire of so many brains struggling for enlightenment with respect to the proper use, sense and consequence of A.P. 970 will remain unsatisfied.

The lift distribution over span and chord governs the stressing of modern high speed aircraft to a large extent, and the chapter dealing with this important question seems to us too short and rather disappointing. One should expect from a book of this kind to find a proper instruction how to calculate lift distributions over given wing systems by means of one or the other of the well known approximate methods.

Apart from this the book can be well recommended. Stress men will enjoy it.

G. W. FEUCHTER: "DIE LUFTWAFFE DER GEGENWART" (The Air Force at Present). 2nd edition. Berlin, 1938. Published by Verlag E. S. Mittler and Sohn. 71 pp., 48 Figs. and 124 photo. tables. Price RM. 2.—.

This booklet is intended as an official instruction manual for personnel serving with the German Air Force, and the well informed author is a former editor of the official periodical "Deutsche Luftwacht." Classification of military aircraft, the history of the German Air Services before and during the war, and the organisation, strategics and tactics of a modern air force are treated. Under reference to the special instruction given in the service, the present German Air Force is dealt with in one and a half pages only.

The historical part is apparently written without any prejudice (see Fig. 26 for instance), but a number of minor mistakes or omissions are incorporated, as for instance Fig. 36 (showing an "Albatros D.III," recte an Alb. D.V built by O.A.W.), the omission of the valuable navy fighting squadrons (Sachsenberg), and of the important work done by the special army long distance reconnaissance flights which became so decisive for the preparation of the offensive of March, 1918, certain statements with regard to the value of types (the Sopwith Camel being considered as the best single-seater fighter of the R.A.F.), etc.

Otherwise a well written book fully suitable for its purpose.

WALTER ZUERL: "SCHWIMMENDE INSELN, FLUGHILFSSCHIFFE, ZWILLINGSFLUGZEUG, ETC. (Floating Islands, Aircraft Auxiliary Ships, Composite Aircraft, etc.). Muenchen, 1938. Published by Carl Pechstein Verlag. 95 pp. with numerous pictures and drawings. Price RM. 3.—.

The theme of this booklet is unique. It is a more or less general survey describing well known proposals and realisation of means for the assistance of transoceanic air traffic. Of special interest and given with many details are the descriptions of the German catapulting ships stationed in mid-ocean and forming seaplane stations which render so valuable an assistance to the transoceanic air services of the Deutsche Luft Hansa. Hoist arrangements and Heinkel catapults and other auxiliary components are illustrated and explained. About one page is devoted to the Mayo Composite Aircraft. As a general information the work can be recommended.

"KOEHLERS' ILLUSTRIERTER FLIEGER-KALENDER" (Illustrated Air Almanac). 1937 and 1938 edition. Minden i.W. Published by Verlag von Wilhelm Koehler. 208 pp., with Fig., tabl. and photo. reprod. Price RM. 1.30 each.

These almanacs are edited for the air-minded German youth, are quite well written and contain a number of valuable historical contributions relating to pre-war and wartime aeronautics, and, as these bring facts hitherto unknown, they might be very often of interest to the non-German reader.

It is astounding to read (Vol., 1937, p. 101) that the famous steel darts used by French pilots early in the war were actually of German manufacture and imported into France a few months before the great war broke out (a sample we owned bore the inscription " Invention Française, Fabrication Allemande," and we always took it for a German imitation of the original French steel dart, for use in the German Air Corps).

CORRESPONDENCE.

To the Editor of the JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY.

DEAR SIR,—In the introduction of his paper Squadron Leader Buxton refers to the possibility of dynamic soaring with sailplanes. He would be a bold man who would say that this is impossible, though certainly its advent does not appear near. The greatest obstacle in its path is no doubt the fact that suitable conditions are likely to obtain near to the ground and therefore to be of little use to the soaring pilot.

The lecturer states that he does not see the birds making use of this method of soaring, but I have a cine film taken by a member of " Discovery II " in the South Seas some years ago, and in this the albatross is seen to keep aloft without flapping, almost endlessly, by a continuous circling flight rising into the wind and diving to the water surface on the down-wind stretch. I was also privileged to see a film at the Wasserkuppe, in 1932 I believe, taken by Professor Idrac, and here again the dynamic soaring of sea birds is unmistakable. I believe the plover takes advantage of this method of flight, particularly during the autumn, when I presume conditions are most favourable.

A little further on, under the heading, " Help from Dynamic Effects," the lecturer mentions the gain of height obtained during the take-off into a high wind. If the pilot then turns and glides, or dives down wind, dynamic soaring is accomplished.

The lecture provides more material than had been anticipated from the lecture heading, but I was a little disappointed that more information concerning the design of sailplanes was not made available. Considerable research has been carried out in connection with such factors as optimum depth/chord ratio of wings, amount and position of maximum camber, and body/wing combinations, and the application of such factors in sailplane design would be appreciated. Then there is the question of variation of thickness and camber over the tip portion of the wing and their effect on tip-stalling. Perhaps the lecturer would also give his views on the advisability of employing a relatively low lift aerofoil, with accompanying low drag for normal soaring flight and rely on slotted, or other flaps for landing? The advantage of Fowler flaps should not be overlooked in this connection.

Could Squadron Leader Buxton indicate how close to, or how far from, the streamline aeroplane of Prof. Melvill Jones the various present-day sailplanes lie? Also it would be interesting to know the reason for the proneness to stalling of the " Kirby Kite." Have any full-scale experiments been carried out with wool tufts, as this would surely be an inexpensive method of obtaining useful data?

The sailplane appears to offer an excellent opportunity for the employment of stressed skin construction, owing to the relatively thick walls available with plywood. Can the lecturer give more information on this important point?

Finally, I cannot agree with the suggested utility of the tailless sailplane, though a semi-retractable tail might be well worth the additional complication. The normal tailless machine has the extra drag of twin rudders, and their interference with the lift curve during circling flight must be serious. The employment of wing-tip " controllers " means reversal of lift along the wing span with considerable spanwise interference. Some years ago I was associated with the

Granger brothers, of Nottingham, in the design of the "Archyopteryx" semi-tailless aeroplane. Originally this was to have been an "orthodox" tailless design, but as time passed it was found convenient for certain reasons to extend the nacelle backward and instal the rudder there. This machine flew strongly for several years and possessed a remarkably fine performance.

The dearth of good soaring craft in this country is due in part to the small demand, but chiefly to the very high cost of producing something that possesses the utmost aerodynamic cleanness, which is essential if our machines are to hold their own in foreign competition.—Yours, etc.,

C. H. LATIMER NEEDHAM.

To the Editor of the JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY.

SIR,—It is interesting to hear of a film showing dynamic soaring by birds. I think that there would be a number of people who have not yet seen it, like myself, who would welcome an opportunity of seeing it.

The optimum thickness of wing sections to be used clearly depends largely on the resistance of the section. It has lately become clear that the values of resistance got in wind tunnel experiment are misleading, and that full-scale tests in the atmosphere are preferable. Thus the actual selection of a section depends on a test which should be made in the atmosphere, and at the actual Reynolds number of the intended design, and such tests have not to my knowledge been done at Reynolds numbers appropriate for sailplanes.

It appears that British aeronautical opinion differs from contemporary German opinion by giving a lower value for the increase of resistance of a section with increase of its thickness.

The curvature of the centre line controls the pitching moment, the maximum lift coefficient, and the form of the stall when combined with the effects due to the thickness and shape of the envelope. The last of these three effects is still a matter for experiment such as the useful family of results recently presented to the Society by Mr. Relf. Incidentally his analysis of the N.A.C.A. family of sections shows that a wing which is tapered in thickness, and of which the root and tip sections have the preferable rear stall, may have some sections intermediate in the span which have a front stall.

I have tried to describe the two systems of designing wing fuselage junctions in the reply to Mr. Baynes. The calculations by Glauert's method of the shape of the fuselage, growth, and wing when they are to be combined in a single lift producing system is naturally a serious piece of work.

For the other method, where the fuselage is designed as a streamlined body to cause the minimum interference with the wing, so many methods have been used successfully, with various types of fillet or with none, that I cannot form an opinion of the best form. From experiments with wool tufts and with pitot tubes on the wing root of the King Kite, I suppose that its junction could be improved.

Mr. Shenstone has discussed the drag of sailplanes; and in the reply to his contribution, I have described the method which I used to select the tip sections of the King Kite from the point of view of control near the stall.

In a tailless design, the drag of the rudders is not increased in proportion to their duplication as their total area need not be increased in that proportion. This is because they are more effective when deflected as their drag as well as their (sideways) lift contributes to the yawing moment desired. Also the area of fin is reduced owing to the directional stability of the swept back wing.

If the taper and twist of the wing and the balance of the sailplane are correct, it does not appear to be necessary to have reversal of lift near the wing tip.

The tailless type appears to have advantages as an aeroplane as well as for a sailplane.—Yours, etc.,

MUNGO BUXTON.

THE
FAIREY
"BATTLE"

INDUS

HIGH-GRADE

ALLOY STEELS

for Automobile & Aero Engine Construction in

BILLETS, BLOOMS, SLABS or BARS

including

CASE HARDENING STEELS
NICKEL CHROME STEELS
CHROME STEELS
CHROME VANADIUM STEELS
NICKEL CHROME MOLYBDENUM
SILICO MANGANESE and SILICO
CHROME SPRING STEELS
VALVE STEELS, etc., etc., DIE BLOCKS

Tool Steels for all purposes.

Write for our High Grade Steel Booklet.

INDUSTRIAL STEELS LIMITED.

SHEFFIELD

Represented in

LONDON, MANCHESTER, BIRMINGHAM, CARDIFF, NEWCASTLE-ON-TYNE, LEEDS, NOTTINGHAM.

AUTHORITATIVE TRAINING

Study with The T.I.G.B., the FIRST Institution of its kind recognised by The Royal Aeronautical Society, and the Premier Correspondence Training Organisation for Aeronautical Students.

Students of The T.I.G.B. have gained TEN FIRST PLACES in the Society's Examinations, including FIRST PLACE IN THE WHOLE EXAMINATION. The T.I.G.B. guarantees training until successful

Write to-day for "The Engineer's Guide to Success" — Free — which contains the widest choice of engineering courses in the world—over 200—and alone gives the Regulations for Qualifications such as A.F.R.Ae.S., A.M.I.Ae.E., Ground Engineers, Air Navigators, Pilot's "B" Licence, A.M.I.Mech.E., A.M.I.E.E., etc.

The Technological Institute of Great Britain,
39, Temple Bar House, London, E.C.4.

Founded 1917. 20,000 *Successes.*

Dunelt

SPECIAL STEELS FOR AIRCRAFT

Conforming to all the Air Ministry and B.S.I. Specifications.

Case-Hardening STEELS
Medium-Carbon STEELS
HIGH TENSILE ALLOY STEELS

DUNFORD & ELLIOTT (Sheffield) LTD.

Attercliffe Wharf Works, Sheffield 9

Grams: "Blooms, Sheffield." Phone: Attercliffe 41121

London Office: 54 Victoria Street, S.W.1
Birmingham Office: 25 Burlington Chambers, New Street.

WE MANUFACTURE THESE—

On Air Ministry Approved List

THE LONDON NAME PLATE Mfg. Co. Ltd.

72-75, TURNMILL ST., CLERKENWELL, LONDON, E.C.2. 'PHONE:- CLERK. 6883-4.

ZYLO WORKS, MARINE VIEW, BRIGHTON 7. 'PHONE:- B'TON. 1876

PARAFILM. A material, unique in its properties, characteristics and applications, much used by Aircraft Manufacturers.

BLACK ADHESIVE INSULATING TAPE. 'Bulldog' Brand

INSULATING MATERIALS in general.

Enquiries invited by :

POMONA RUBBER COMPANY

Openshaw Bridge Works, Manchester, 11

Telegrams : Pomrub, Manchester Telephone : East 0316

For Optimum Hardness and Strength

NITRIDED

NITRALLOY STEEL

Particulars from

NITRALLOY LIMITED

Norris Deakin Buildings, King Street, SHEFFIELD 3

Telephone : 25759 SHEFFIELD Telegrams : NITRALLOY SHEFFIELD

EBONITE AND COMPOSITE MATERIAL

RODS, TUBES, SHEET, MOULDINGS, TURNING

OF ALL DESCRIPTIONS

Manufacturers :

THE BRITISH EBONITE Co. Ltd. (BECOL)

HANWELL, LONDON, W.7

Regd. Trade Mark

Luftfahrtforschung

publishes the works of the most important German institutes of research in the field of flying technics.

Trial number and prospectus free of charge. 12 numbers are published yearly.

Price per year :

Germany : RM.24.— Other Countries : RM.18.—

Publisher : R. Oldenbourg, München I (SchlieBfach 31)

INDEX TO ADVERTISERS

Acheson, E. G. Ltd. xxvi
Aeronautical Sciences, Journal of the xiv
Airspeed Aeronautical College ... xviii
Armstrong Siddeley Motors, Ltd. xv
Armstrong Whitworth, Ltd. ... xi
Askania Works, Ltd. ... ... —
Automotive Engineering Co., Ltd. xxvii
Automotive Products Co., Ltd. ... —

Birmetals, Ltd. xix
Blackburn Aircraft, Ltd. vi
Bristol Aeroplane Co., Ltd. (Aircraft) xxxii
Bristol Aeroplane Co., Ltd. (Engines) *Back Cover*
British Aviation Insurance Co., Ltd. xx
British Ebonite Co., Ltd. xxxv
British Piston Ring Co., Ltd. ... xiv
British Thomson-Houston Co., Ltd. xxiv
Brown, E. xviii

Cellactite & British Uralite Co., Ltd xii
College of Aeronautical Engineering xxxi
Corrugated Packing & Sheet Metal Co., Ltd. ... ... —
Coventry Climax Engines, Ltd. ... xxv

Dunford & Elliott, Ltd. xxxiv
Dunlop Rubber Co., Ltd. xxxvii

Ebonestos Industries, Ltd. ... ... —
English Steel Corporation, Ltd. —

Fairey Aviation Co., Ltd. xxxiii
French, W. T., & Son, Ltd. ... —

General Aircraft, Ltd. xx

Habershon, J. J. & Sons, Ltd. ii
Handley Page, Ltd. iv
Hawker Aircraft, Ltd. xxviii
High Duty Alloys, Ltd. vii
Hills, F. & Sons, Ltd. xvi
Hobson, H. M. (Aircraft & Motor) Components, Ltd. xviii
Hughes, F. A., & Co., Limited xiii

Imperial College of Science and Technology ... ... —
Industrial Steels, Ltd. xxxiv

Jablo Propellers, Ltd. ... ... —

King, G. W. Ltd. xxix

Lodge Plugs, Ltd. xxii
London Aluminium Co., Ltd. ... —
London Name Plate Co., Ltd. ... xxxiv
Luftfahrtforschung xxxv

Mason, E. N. & Sons, Ltd. ... —
Mavitta Drafting Machines, Ltd. —
McGraw-Hill Publishing Co., Ltd. xxix

Napier, D. & Son, Ltd. ... ... —
Nitralloy, Ltd. xxxv

Palmer Tyres, Ltd. xxi
Pitman, Sir Isaac, & Sons, Ltd. x
Pomona Rubber Co. xxxv
Priestman, T. J., Ltd. ii

Roe, A. V. & Co., Ltd. xxii
Rolls-Royce, Ltd. v
Rotax, Ltd. ix
Royal Air Force Quarterly viii
Rubery Owen & Co., Ltd. ... ... —

Shell-Mex and B.P., Ltd. ... ... —
Short & Mason, Ltd. xxviii
Short Bros. (Rochester and Bedford), Ltd. *Back Cover*
Simmonds Development Corporation, Ltd. xxxvi
Smith's Aircraft Instruments, Ltd. xvii
Supermarine Aviation Works (Vickers), Ltd. ... ... —

Technological Institute of Great Britain xxxiv

Vickers (Aviation), Ltd. iii
Vulcanised Fibre, Ltd. xxiii

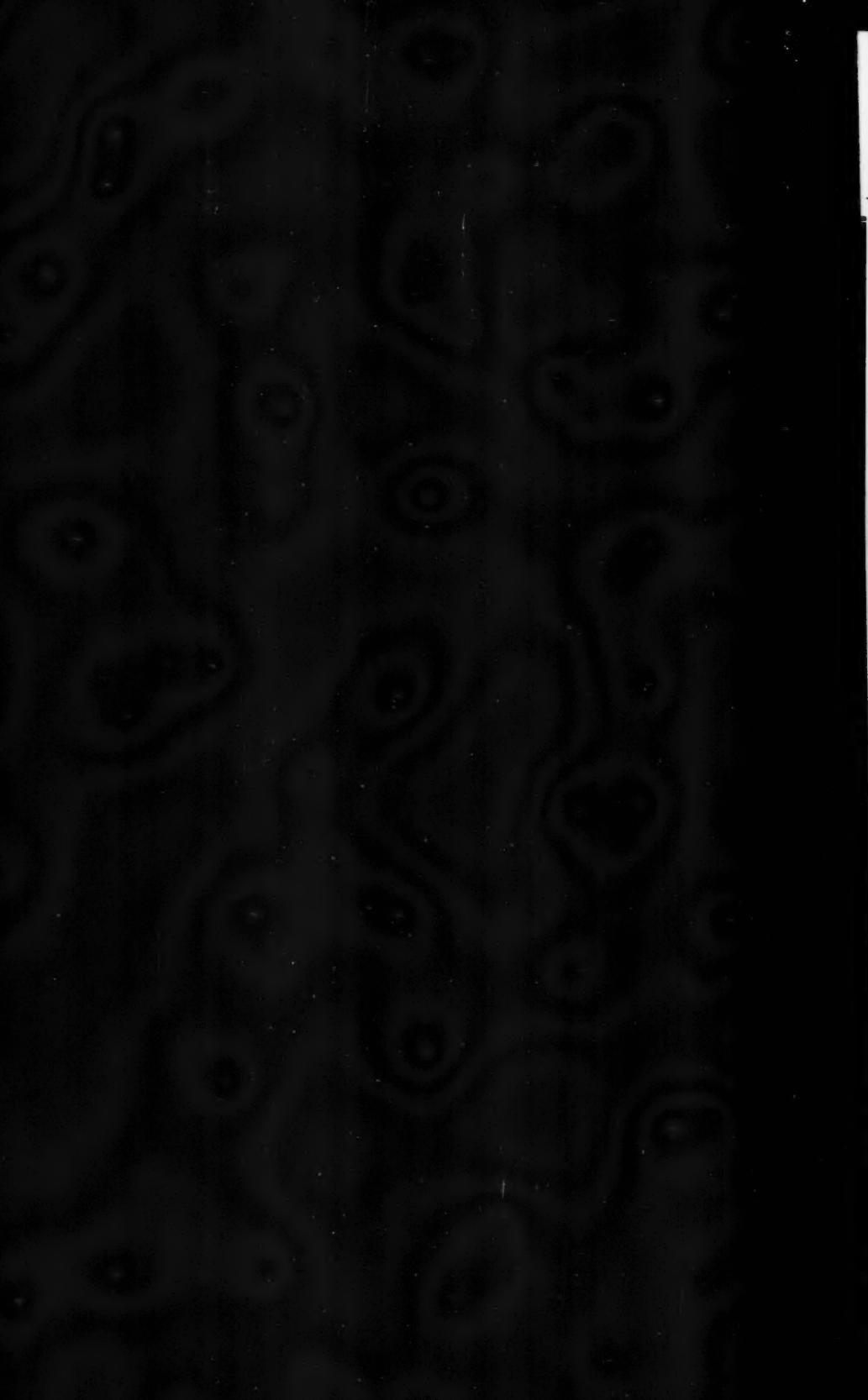
Wakefield, C. C. & Co., Ltd. ... —
Walter, Ltd. xxx
Wellworthy Piston Rings, Ltd. xvi
Westland Aircraft, Ltd. xxi
White, J. Samuel, & Co. xxxii

SIMMONDS DEVELOPMENT CORPORATION LTD.
SHELL MEX HOUSE, LONDON, W.C.2

Seeks in all countries new types of aircraft accessories and components, preferably patented, for development and production by the manufacturing companies of the

Simmonds Group

throughout the World.

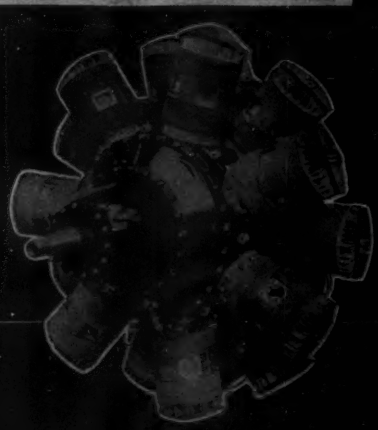


1888
1938
DUNLOP
AEROPLANE TYRES,
WHEELS AND BRAKES

"BRISTOL" AERO-ENGINES

power many of the world's most notable aircraft and were chosen for manufacture under the "Shadow" scheme because of their proved "high performance with reliability."

"Bristol"

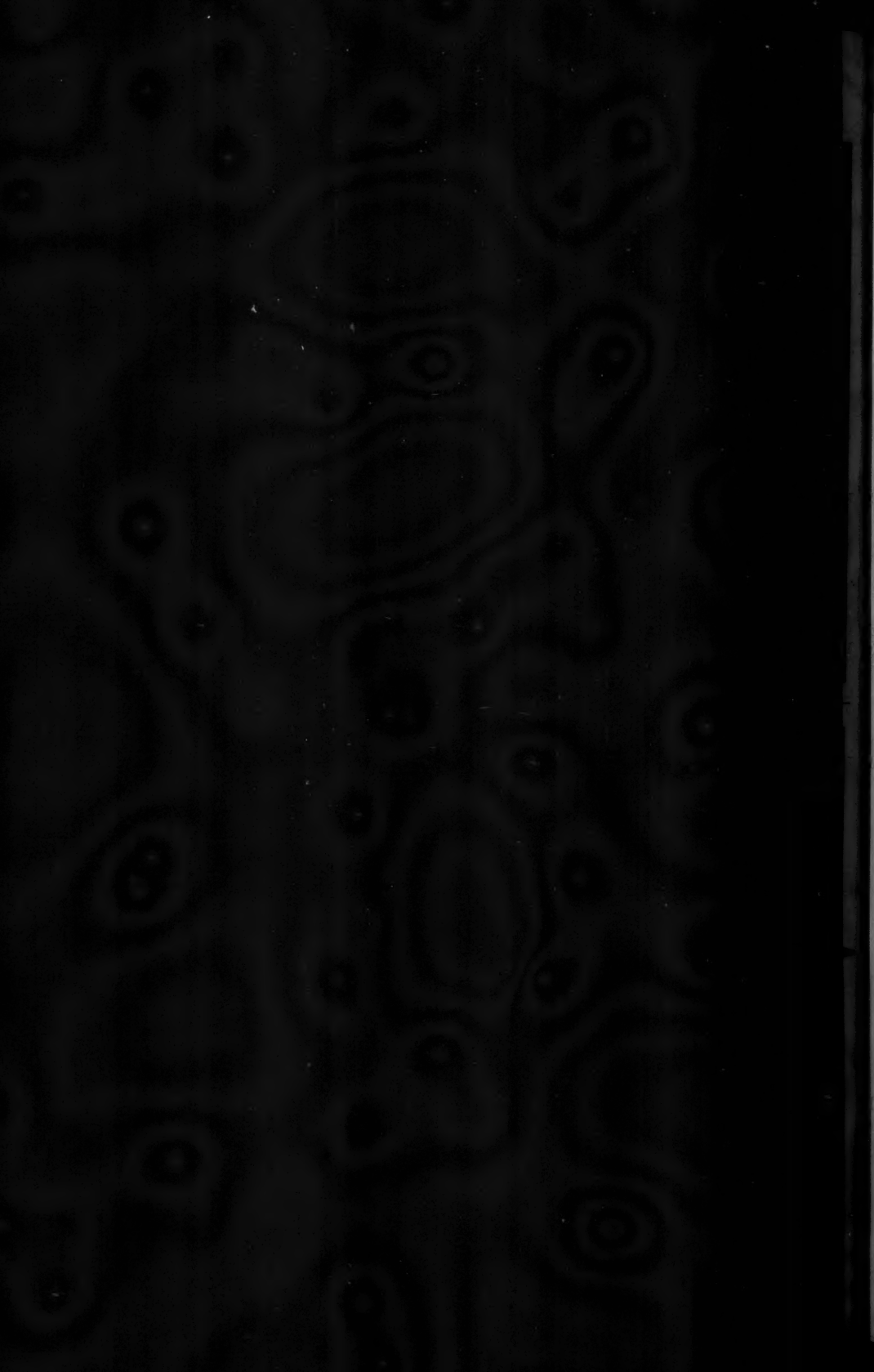


THE BRISTOL AEROPLANE CO. LTD. FILTON, BRISTOL

THE EMPIRE FLYING BOAT

SHORT BROS. (ROCHESTER & BEDFORD) LTD.
ROCHESTER

Printed by The Lewes Press (Wightman & Co., Ltd.), Friars Walk, Lewes, England, and Published by the Royal Aeronautical Society, 7, Albemarle Street, London, W.1, England.



SOME CONSIDERATIONS ON THE REACTION OF WIND UPON SAILS.

Lieutenant-Colonel J. T. C. Moore-Brabazon, F.R.Ae.S.

The study of the problems connected with a successful racing sailing boat, like Gaul, can be divided into three parts. There is first of all the general configuration of the hull upon which lately much study has been directed. Anybody interested in this should look up the article, " Model Tests of Sailing Yachts," by Kenneth S. M. Davidson, Director, Experimental Towing Tank, Stevens Institute of Technology, New Jersey, appearing in the August issue of " The Rudder," in which it will be noted model hulls are pulled through the tank at an angle of heel, and with an angle of drift. These conditions have hitherto not been adopted in tank tests. Too, there is manœuvre in which the tactics and rules must be known and appreciated, and upon which there has been much written. Finally, there is the motive power which is derived from the reaction of wind upon the sails. In such a paper as the Royal Aeronautical Society Journal the last consideration alone deserves attention as it is undoubtedly an aeronautical problem. I have mentioned before the fact that the ordinary sailor, even if he be an experienced helmsman, has regarded the advent of aeronautics relative to the sails of a boat with the same composure and lack of interest as a cow views a passing train! On the other hand, the aeronautical engineer is rather liable to look at the sailing boat as a very simple aeronautical problem, and in view of the fact that there is little money to be made out of its construction has neglected it. Let me, however, disabuse the aeronautical engineer of a belief that the problem is a simple one. The designing of aircraft is child's play compared with the difficulties of the sailing boat.

First of all there is the fact that the surfaces are single surfaces, they can't be made to hold a rigid shape; their curve is a function of the cut of the sail and of the speed and angle of wind; there is no definite speed to which they are designed to get reaction from the air, this varies from zero to gale force; the problem is complicated by changing angle due to the heel of the boat when pressure is applied, by the fact that the air does not come true to the sail even, it has to advance over sometimes rough sea and finally over the hull of the boat. Then the aerofoil is presented at every angle, first the problem " on a wind " is one of high lift drift ratio, then as angles change we must be efficient until the wind is completely aft and normal to the sail, when lift to drift ratio becomes unity. These conditions as one approaches the drawing board are indeed perplexing, added to which the fact that whatever is introduced must be practicable as I know to my cost, many things which look very nice on paper become a very grave embarrassment, and indeed a danger, when it starts to blow!

Constructions of rig on a small boat have appealed to the author for many years and various rigs have been tried out on a class of boat in the Solent known as the Redwing class, a class singularly suitable for experiments. Hull formation difficulties are got over by the fact that all hulls are made identical in shape. Rig is free from the point of view of design, the only consideration being that total surface should be 200 square feet and not more.

With this in view, in 1922 I made a single sail attached to a streamline rotating mast and had a boom which bent on close hauling, a band brake was put on the rotating mast, which, when a final haul was given to the sheet, bent the boom and imposed a curve which was rigidly complied with right up the sail by virtue of battens which lodged into the streamline mast.

Later I introduced a gaff mainsail in which the gaff could be controlled, and still later (1930) I rigged a bipod mast, designed by Manfred Curry with the sails starting on a luff wire and the boom projecting further forward from which a jib was attached. These rigs should, I think, at the time have been described with their merits and demerits in your columns. I, however, must bear the blame for this omission.

At a later date, in 1934, I introduced the principle of the autogyro, the working of which was, however, described in the ROYAL AERONAUTICAL SOCIETY JOURNAL (September, 1934).

This year, not entirely content with the standard rig, I fitted the boat out in accordance with the rig designed by Dr. Ljungström, of Sweden, which looked as if it had very great aeronautical advantages, and upon which some practical work has already been done in Sweden.

I had my attention drawn to Dr. Ljungström's rig by Mr. Frank Andreae, and due to his kindness I was enabled to equip my boat similarly to his with all

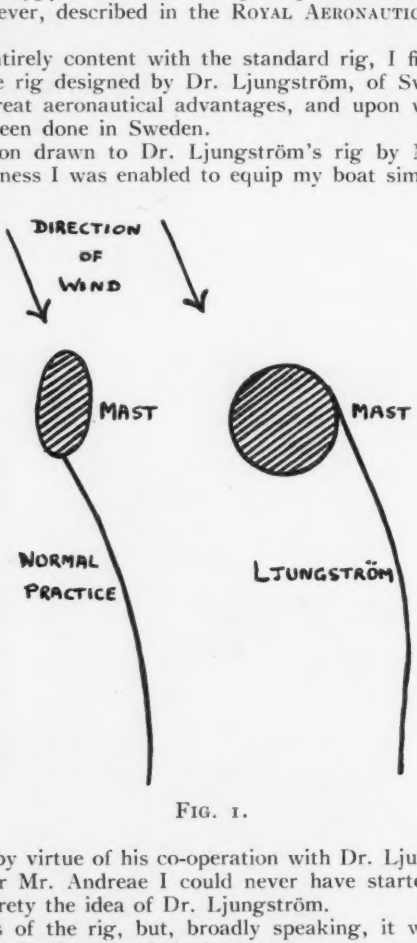


FIG. 1.

the necessary gear by virtue of his co-operation with Dr. Ljungström, in Sweden. Had it not been for Mr. Andreae I could never have started with a rig which embodied in its entirety the idea of Dr. Ljungström.

I append pictures of the rig, but, broadly speaking, it was a single aerofoil rather like my first sail of 1922. It had no stays except one from the top of the mast right aft. It was, therefore, altogether free from parasitic drag, which is a very considerable advantage when sailing "on a wind." The mast weighed sixty pounds more than the standard mast and by view of the fact that the sail was all in one it had to be stepped forward more than normally. A heavy mast stepped forward in a boat of long water line and over hang is not very much of a handicap, but in a small boat it is a definite disadvantage, as the general rising and falling of the bows in short seas makes the pounding more vigorous due to the forward weight than in the ordinary rig, but I am not blaming this particular disadvantage as of paramount importance, although I mention it as being

definitely a disadvantage, but where other considerations are wholly advantageous it might be ignored.

The mast went through the deck and was fitted with a ball-bearing both at the foot and on deck. The side thrust, giving heel to the boat, was taken through the planking of the deck; immediately under the deck was fitted a wheel of about 2ft. 6ins. in diameter, the centre of which was the mast to which it was keyed, round the disc ran a rope which was then passed round inside of the hull so that the mast could be rotated easily from any position in the boat. The sail ran up the mast in the usual slot. The sail had no boom and was sheeted centrally aft, there being no horse. The general idea of the rig was by rotating the mast, always to be to windward, to get the air upon the lee side of the sail, uninterrupted by the burble which must necessarily follow any aerofoil entering the air with a projection on the lee side (see Fig. 1).

To the uninitiated it must be realised that since the introduction of the Bermuda rig, instead of the sail being attached to the mast by rings, in which case the mast is central to the luff, the sail in the Bermuda rig is hoisted either in a groove in the mast or on what is called a tramway. It will be seen consequently that when " on a wind," the mast stands on the lee side of the sail, and this is a grave disadvantage in view of the fact that it will disturb the lee side and cause a breakdown of the air flow, which for efficiency should continue smoothly to the end of the sail. In the Ljungström rig, when " on a wind," the mast is rotated so that no part of the mast is on the lee side of the sail. The sail, consequently, although fouled on the windward side by the whole diameter of the mast, starts free and clean on the lee side. Dr. Ljungström attaches very great importance, very rightly, to this, irregularities on the pressure side of the sail being comparatively innocuous, but " on a wind " on the lee side it was important that there should be perfect smoothness of air. The general appearance of the boat, as will be seen from the picture, is a little odd and would be distrusted by the standard sailor.

Reefing is done by rotating the mast, whereupon the sail winds up completely round the mast until there is nothing left, battens being inserted vertically. The sail can be exposed or reefed in accordance with the amount the mast is rotated.

Let me say, as one who has tried this rig out, it is a completely satisfactory sailor-like job and for ordinary cruising is practical and very free from that distressing macaroni of ropes which is generally found at the bottom of a small boat. But the beauty of being able to come up to your moorings, slowly revolving your mast till no sail is left, wants to be experienced to be really appreciated.

Now I want to describe how this particular rig worked in racing, as it was designed as a racing rig and in the Redwing class is tried out against some of the most modern of rigs and some of the best helmsmen. As to helmsmanship, I do not know quite how to class myself. If one can talk golf parlance I should not describe myself as " scratch," I should call myself handicap six. That is the only way I know of describing skill at a particular job, for I would not like the impression to go abroad that the boat was tried with the highest degree of skill, but with a certain amount.

Now the chief desire of anybody sailing a boat is that it should go well " on a wind." With this boat pointing at its highest it was quite astonishing from the point of view of efficiency. I think it would be admitted by anybody who has seen it that at a high point it stood alone compared with any other rig. On a run the original rig had a double sail, one of which went each side of the mast rather like a butterfly. This I was unable to use as I was strictly limited as to sail area. In running and in broad reaches the sail did not set so well without a boom. Consequently I carried a temporary boom which I fitted for these particular angles in sailing. In running, the boat was as good as any ordinary one and reaching at right angles to the wind was about as good as any of the boats. The reason for this article, however, is the peculiar results

which occurred at one particular point of sailing. I have already paid tribute to this rig when " on a wind "; there you are presenting the sail at the highest point possible in sailing, round about 30° to the wind. As I said, this rig was particularly efficient, but sailing is not always " on a wind," so many times the course is just " off the wind," and the difference between " on a wind " and just " off a wind " with this particular rig was quite astonishing. In racing I would

FIG. 2.

be holding my own with the leading boats and creeping up to them, and eating up into the wind, when the wind to the mark would free itself, and it did not then become the highest point possible, but just a high reach. From that moment, instead of being able to hold my own, I was quickly, and astonishingly quickly, passed by other normally rigged boats in the class. The explanation of this is, I think, interesting. When the angle of attack becomes coarser, air

can no longer cling to the lee side, and a state of " stall " occurs. Now a " stall " in aeroplanes occurs at a critical time and within a very narrow range, and the pilot is instantly aware of what has occurred. No such knowledge is possessed by the sailor. When the " stall " occurs when sailing, although the reaction of the sail from the point of view of the drive of the boat must be very considerable, yet it is not demonstrable or detectable. Since this is not apparent, unless one is sailing against another boat and realises their sudden acceleration, one could continue unaware of the fact of the " stall." Why the other boats continued their efficiency when just " off the wind " was due, of course, to the fact of their jibs pouring air upon the lee side of the sail and consequently stopping the " stall."

I think I have been disrespectful to sailors in the beginning of this article. It is interesting to note that the introduction of a jib to the fore and aft rigged sailing boat was in fact the original Handley Page slot. Its advantages were appreciated by sailors many years before Mr. Handley Page invented it for aeroplanes, but to this day most sailors do not appreciate the significance of the advantages they possess in the jib. In the Ljungström rig the desirability of fitting a stop to the breakdown of air on the lee side of a sail when sailing just " off the wind " is demonstrated in the most convincing way—in other words, it badly wants a jib, and a jib cannot be fitted.

From these considerations I now want to pass to some general remarks, which might be of interest to those aeronautically inclined, who sail boats. In aeronautical design the position of the slotted wing is one of great complexity of adjustment, but here, of course, speeds are known and the construction and the position can be determined for known velocities of wind. In boats, however, what should be the separation between the jib and the mainsail? This separation must be judged and becomes a separation only from the point of view of from where the wind is coming. It is difficult to express, but the separation is, of course, zero if you look directly from the bow of the boat and opens out gradually as one views it from increasing angles. When " on a wind," when the boat is at an angle of about 40° to you the separation is small, however much forward relative to the mast the jib may be, and consequently the stream of air from the jib is directed always fairly efficiently on to the lee side of the mainsail. Now then, supposing one gets " off the wind " a little, as has been shown by the Ljungström rig. The " stall " can be avoided if the wind from the jib on the lee side can be maintained, but the separation between the two sails as angles of attack become coarser now becomes more and more separated, always being viewed from the direction the wind is coming. What is the greatest separation possible between two sails still to stop breakdown on the leeside of the mainsail? As one gets a coarser angle there must come a time when the " stall " occurs. At what angle does it occur? This question must then be asked: Would it be an advantage when sailing " off the wind " to bring the jib back towards the mainsail in order to maintain the flow on the lee side of the mainsail? If that could be done in an ordinary rigged boat then I believe there would be one point of sailing with a jib well aft that would give a great advantage. The experienced sailor will say if this be done it will mean that the side thrust on the boat will become unbalanced and the boat will carry helm. This drag would be against the aeronautical advantages of the sail. Only experience will show the balance of advantage. My experience this year in sailing the Ljungström invention, on which I congratulate Dr. Ljungström, has made patent to me, however, in a very convincing way the desirability of following what happens on the lee side of a sail to such an extent that I thought it might be of interest to some who take perhaps only an academic interest in sailing, but whose aeronautical knowledge is great, to worry over it and give their comments in their spare time. I do not promise them a fortune, they will not get the fame of Nelson, but if I, in any way, introduce them to the delights and complexities of competitive sailing, I shall deem these few words worth while.

THE STRESSING OF A TAIL BOOM SYSTEM FOR FIN AND RUDDER SIDE LOADS.

By J. Morris, B.A.

Introduction.

In certain types of aeroplane the empennage is carried on two tail booms emanating from the main body. In some cases the booms and tail plane form what is virtually a portal and in these circumstances a fairly simple approximation may be found for the stresses resulting from fin and rudder side loads. The method adopted follows the treatment given in the author's paper, " The Stressing of Rigid Jointed Frames."*

§1. Deformation of a Single Member of a Plane Frame.

Referring to Fig. 1, let AB be the displaced position of a uniform member originally at A_oB_o when the frame is unloaded. If the member carries no distributed load and M_{AB}, M_{BA} are the moments exerted by the appropriate joints on the ends of the member, measured positive clockwise, then

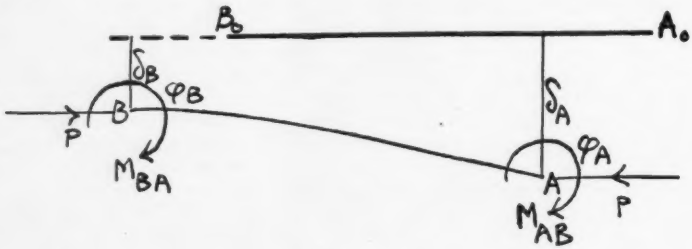


Fig. 1.

$$M_{AB} = -\{6EI/l^2\}\{\delta_{AB}/\phi(a/2)\} + \{4EI/l\}\{\phi(a)/\psi(a)\}\phi_A + \{2EI/l\}\{f(a)/\psi(a)\}\phi_B,$$

and

$$M_{BA} = -\{6EI/l^2\}\{\delta_{AB}/\phi(a/2)\} + \{2EI/l\}\{f(a)/\psi(a)\}\phi_A + \{4EI/l\}\{\phi(a)/\psi(a)\}\phi_B,$$

where E, I, l refer to the flexural stiffness of the member, ϕ_A, ϕ_B are the angular rotations of the ends, measured positive clockwise,

$$\delta_{AB} = \delta_A - \delta_B,$$

$a = (l/2)\sqrt{(P/EI)}$ where P is the end load in the member, and $f(a)$, $\phi(a)$, $\psi(a)$ are the Berry functions,

$$f(a) = 6(2a \operatorname{cosec} 2a - 1)/(2a)^2,$$
$$\phi(a) = 3(1 - 2a \cot 2a)/(2a)^2,$$
$$\psi(a) = 3(\tan a - a)/a^3,$$

when the load is compressive. If the load is tensile we use the corresponding expressions

* The stressing of rigid jointed frames. J. Morris. Journal of Royal Aeronautical Society, June, 1936.

$$F(\alpha) = 6(1 - 2\alpha \operatorname{cosech} 2\alpha)/(2\alpha)^2,$$
$$\Phi(\alpha) = 3(2\alpha \coth 2\alpha - 1)/(2\alpha)^2,$$
$$\Psi(\alpha) = 3(\alpha - \tanh \alpha)/\alpha^3.$$

When α vanishes, *i.e.*, when end load deflection effects are negligible or ignored then all these functions are unity.

The shears on the joints due to these moments will be

$$S_{AB} = (M_{AB} + M_{BA} + P\delta_{AB})/l$$

downwards at A and upwards at B.

It may be shown that

$$S_{AB} = \{ -12\, EI/l^3 \} \{ \delta_{AB}/\psi(\alpha) \} + \{ 6\, EI/l^2 \} \{ (\phi_A + \phi_B)/\phi(\alpha/2) \}.$$

§2. Outline of Problem.

Referring to Fig. 2, $A_oA_1B_1B_o$ is a portal encastré at A_o and B_o and having loads W applied at the points A_1B_1 along the line A_1B_1 and couples G applied at the same points with their respective axes along A_oA_1 and B_oB_1. It is required to find the loads, bending moments and torques in the members.

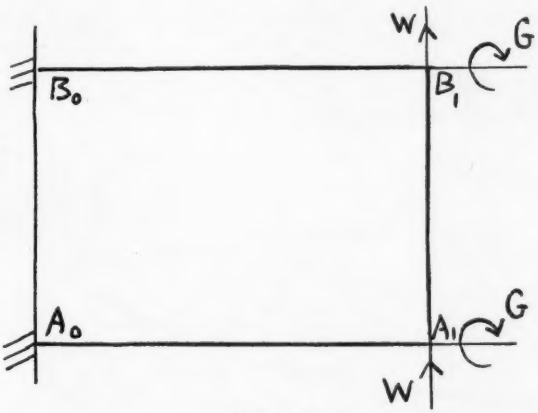


Fig. 2.

§3. Equations of Equilibrium for the Load System W.

Let A_oA_1, B_oB_1 be similar members and let A_1B_1 be symmetrical about its mid point; then, taking the case of the W's alone we may, by neglecting end load deflection effects, assume that the portal will distort in its own plane and with equal extent at both A_1 and B_1. Thus if δ is the deflection of A_1 in the direction A_1B_1 and ϕ is the clockwise angular rotation of the joint A_1, then we may assume as a first approximation that δ, ϕ also apply to B_1. In these circumstances we have the following moments with axes normal to the portal

$$M_{A_1A_o} = (6\, E_1I_1/l_1^2)\,\delta + (4\, E_1I_1/l_1)\,\phi,$$
$$M_{A_1B_1} = (6\, E_2I_2/l_2)\,\phi,$$

the members being assumed uniform and E_1, I_1, l_1 refer to A_1A_o, B_1B_o and E_2, I_2, l_2 to A_1B_1.

For equilibrium of the joint A_1

$$M_{A_1A_o} + M_{A_1B_1} = 0,$$
$$i.e.,\ 6e_1(\delta/l_1) + 4e_1\phi + 6e_2\phi = 0 \quad . \quad . \quad . \quad . \quad (1)$$

where $e_1 = E_1I_1/l_1$ and $e_2 = E_2I_2/l_2$.

Considering the equilibrium between the downward shears at A_1 and B_1 and the external loads we have

$$12\, e_1\,(\delta/l_1^2)+6\, e_1\,(\phi/l_1)-W=0 \quad . \quad . \quad . \quad . \quad (2)$$

As the shears at A_1, B_1 are by supposition equal there is no resultant end load in A_1B_1.

From equations (1) and (2) we find

$$\delta=\{\,(2\, e_1+3\, e_2)/6\, e_1\,(e_1+6\, e_2)\,\}\, Wl_1^2,$$

and

$$\phi=-Wl_1/2\,(e_1+6\, e_2).$$

We thereby obtain

$$M_{A_1A_0}=\{\,3\, e_2/(e_1+6\, e_2)\,\}\, Wl_1,$$
$$M_{A_0A_1}=\{\,(e_1+3\, e_2)/(e_1+6\, e_2)\,\}\, Wl_1,$$
$$M_{A_1B_1}=-\{\,3\, e_2/(e_1+6\, e_2)\,\}\, Wl_1.$$
$$\text{Also } M_{B_1A_1}=M_{A_1B_1}$$

The shears at A_1, B_1 will be

$$(1/l_2)\,(M_{A_1B_1}+M_{B_1A_1})=-\{\,6\, e_2l_1/(e_1+6\, e_2)\, l_2\,\}\, W.$$

These shears will induce a tensile end load in A_0A_1 and an equal compressive end load in B_0B_1.

§4. Equations of Equilibrium for the Load System G.

In this case we may assume distortion as in Fig. 3.

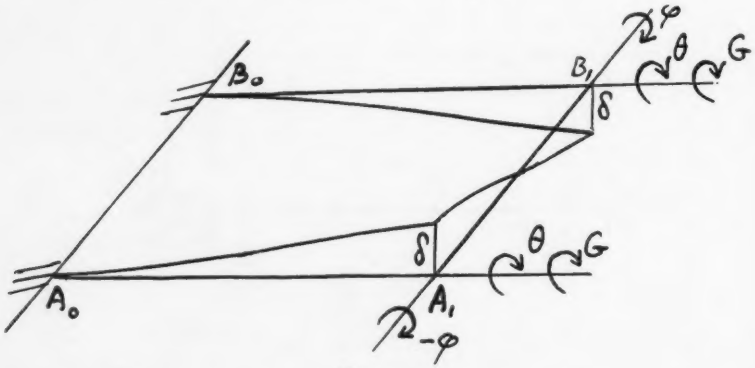


Fig. 3.

Taking flexure normal to the plane of the portal we have

$$M_{A_1A_0}=6\, e_1\,(\delta/l_1)-4\, e_1\phi$$

where the e_1 is appropriate to the flexure considered.

The relative angular rotation between A_1 and B_1 is 2ϕ and so if c_2 is the torsional stiffness of the member (*i.e.*, c_2 corresponds to CI/l of a uniform member of circular section) then the torque in the member A_1B_1 is $2\, c_2\phi$.

The equation of equilibrium for the moments and torques at A_1 or B_1 in the direction of ϕ is therefore

$$6\, e_1\,(\delta/l_1)-4\, e_1\phi-2\, c_2\phi=0 \quad . \quad . \quad . \quad . \quad (3)$$

Similarly for the equilibrium of moments and torques in the direction of θ

$$-12\, e_2\,(\delta/l_2)+6\, e_2\theta+c_1\theta=G \quad . \quad . \quad . \quad . \quad (4)$$

And from the equilibrium of the shears at A_1 and B_1

$$12\, e_1\,(\delta/l_1^2)-6\, e_1\,(\phi/l_1)+24\, e_2\,(\delta/l_2^2)-12\, e_2\,(\theta/l_2)=0 \quad . \quad (5)$$

From equations (3), (4) and (5)

$$\delta = 12\,(4\,e_1 + 2\,c_2)\,(e_2/l_2)\,(G/\Delta),$$
$$\phi = (72\,e_1 e_2/l_1 l_2)\,(G/\Delta),$$

and

$$\theta = 12\,[(4\,e_1 + 2\,c_2)\,(e_1/l_1^2 + 2\,e_2/l_2^2) - 3\,e_1^2/l_1^2]\,(G/\Delta)$$

where

$$\Delta = 12\,(6\,e_2 + c_1)\,(4\,e_1 + 2\,c_2)\,(e_1/l_1^2 + 2\,e_2/l_2^2)$$
$$- 36\,(6\,e_2 + c_1)\,(e_1^2/l_1^2) - 144\,(4\,e_1 + 2\,c_2)\,(e_2^2/l_2^2).$$

We can now obtain the moments and torques as follows:—

$$M_{A_1A_0} = 6\,e_1\,(\delta/l_1) - 4\,e_1\phi,$$

or

$$M_{A_1A_0} = (144\,e_1 e_2 c_2/l_1 l_2)\,(G/\Delta).$$

$$M_{A_0A_1} = 6\,e_1\,(\delta/l_1) - 2\,e_1\phi,$$

or

$$M_{A_0A_1} = \{\,144\,e_1 e_2\,(e_1 + c_2)/l_1 l_2\,\}\,(G/\Delta).$$

$$M_{A_1B_1} = -12\,e_2\,(\delta/l_2) + 6\,e_2\theta,$$

or

$$M_{A_1B_1} = \{\,72\,e_1 e_2\,(e_1 + 2\,c_2)/l_1^2\,\}\,(G/\Delta).$$

Also $M_{B_1A_1} = M_{A_1B_1}$

Torque in $A_1A_0 = 12\,c_1\,[(4\,e_1 + 2\,c_2)\,(e_1/l_1^2 + 2\,e_2/l_2^2) - 3\,e_1^2/l_1^2]\,(G/\Delta)$.

Torque in $A_1B_1 = \{\,144\,e_1 e_2 c_2/l_1 l_2\,\}\,(G/\Delta)$.

The end loads, end moments and torques in the members now being known, their stressing can be readily carried out.

To take a numerical example:—

(i) For the W case let

$W = 1{,}940$lb.
$l_1 = 136$in., $l_2 = 147$in.
$e_1 = 1.36 \times 10^6$lb. in., $e_2 = 26.4 \times 10^6$lb. in.

With these values we find

$\delta = 2.2$in.
$M_{A_1A_0} = 131 \times 10^3$lb. in.
$M_{A_0A_1} = 133 \times 10^3$lb. in.
$M_{A_1B_1} = -131 \times 10^3$lb. in.
$M_{B_1A_1} = M_{A_1B_1}$

End load in A_0A_1 (tensile) or B_0B_1 (comp.) = 1,780lb.

(ii) For the G case let

$G = 65 \times 10^3$lb. in.
$l_1 = 136$in., $l_2 = 147$in.
$e_1 = 20.3 \times 10^6$lb. in., $e_2 = 0.823 \times 10^6$lb. in.
$c_1 = 2.115 \times 10^6$lb. in., $c_2 = 1.06 \times 10^6$lb. in.

With these values we find

$\delta = 0.16$in.
$M_{A_1A_0} = 3.7 \times 10^3$lb. in.
$M_{A_0A_1} = 75.3 \times 10^3$lb. in.
$M_{A_1B_1} = 42.3 \times 10^3$lb. in.
$T_{A_1A_0} = 21.68 \times 10^3$lb. in.
$T_{A_1B_1} = 3.7 \times 10^3$lb. in.

ABSTRACTS FROM THE SCIENTIFIC AND TECHNICAL PRESS.

Issued by the
Directorates of Scientific Research and Technical Development, Air Ministry.
(Prepared by R.T.P.)

No. 59. SEPTEMBER, 1938.

Mineral Deposits of Strategic Importance in the Countries Bordering on Greater Germany. (P. Ruprecht, W.T.M., Vol. 42, No. 7, July, 1938, pp. 296-300.) (59/1 Germany.)

The following table gives the principal conclusions:—

Mineral.	Per cent. of total requirements met by home production.	Possible external source of supply.
Coal	100 per cent.	——
Iron ores	40 ,, ,,	France
Oil	15 ,, ,,	Roumania, Russia
Copper	12 ,, ,,	Jugoslavia
Zinc	100 ,, ,,	——
Lead	31 ,, ,,	Jugoslavia
Aluminium	?	Jugoslavia, Hungary
Manganese	16 ,, ,,	Czechoslovakia?
Mercury	20 ,, ,,	——

Other important mineral, such as nickel, chromium, tungsten, molybdenum, antimony and tin are not produced in measurable quantities either in Germany or in the territories within reach of its boundaries.

Application of Statistical Analysis to Ballistic Problems. (L. Filloux, Revue d'Artillerie, Vol. 120, Dec., 1937, pp. 429-457.) (59/2 France.)

The proper evaluation of gunnery (ballistic) tests requires the knowledge of a certain number of factors pertaining respectively to the gun, the shell and the trajectory.

The author shows that a minimum of 26 factors are necessary to fully define the conditions underlying the test (gun 6, shell 10, trajectory 10). By a proper system of nomenclature, each factor can be expressed by a number which may range from 1 to 6 digits. These numbers represent 80 separate columns marked on a special index card. The numbers are not written in by hand, but holes are punched by a special machine in appropriate positions. Each card expresses the results of one ballistic test, and by means of the holes, the cards can be readily sorted out mechanically so that all the cards of one set will have one factor number in common. Repeated sorting shows the effect of variation of one or more factors on the others.

As an example, suppose 6,000 cards are available representing more or less complete results of 6,000 tests on a certain gun. It is required to obtain the variation in range and displacement relative to target with length of projectile fired and state of wear of gun.

With the machine these factors can be separated within 2½ hours, using unskilled labour. If the analysis is carried out without mechanical help, the author reckons that at least one month will be required using two fully trained assistants.

The Effect of the Weather on the Spotting of Aircraft by Sound Waves. (D. Lautner, Luftwehr, Vol. 5, No. 7, July, 1938, pp. 282-284.) (59/3 Germany.)

The rays of sound are only straight lines if the atmosphere is at a uniform temperature and at rest. The normal temperature lapse rate (.6°C. per 100 m.) causes the sound rays to bend upwards, the radius of curvature being of the order of 100 k.m. Similar deflections are produced by the presence of wind. In this case, however, the curvature is no longer symmetrical with regard to the source. An increase in wind velocity with altitude of the order of 1 m/sec. per 100 m. is approximately equivalent to a decrease in temperature of 1.7°C. per 100 m. altitude on the windward side of the source together with an increase of the same amount on the lee side.

The rays of sound are thus bent downward on the lee side and the area of response considerably increased. Beside these relatively simple effects due to continuous change in temperature and wind speed, the sound wave may be reflected, if there is a sudden change in these factors. For temperature jumps of the order of 10° or changes in wind speed of the order of 5 m./sec., the limiting angle for total reflexion is of the order of 80°.

In addition, acoustical spotting is complicated by the phenomena of absorption and dispersion, both of which depend markedly on atmospheric conditions.

Replacement of Aircraft Material During the World War. (Luftwehr, Vol. 5, No. 7, July, 1938, p. 279.) (59/4 Great Britain.)

According to calculations carried out by Jones (The War in the Air), in order to maintain a squadron of 18 British aircraft at full strength, a further 18 aircraft were required, of which:—

6 were available as immediate reserves,
6 were stationed in close proximity to the front aerodrome,
6 were used at home for training.

On the Western Front, the average monthly losses amounted to:—

66 per cent. of the fighters (single seat)
50 ,, ,, ,, ,, ,, (two seat)
50 ,, ,, of the reconnaissance
33 ,, ,, of the bombers.

On the other fronts, the average losses only amounted to 20 per cent.

The Composition of the Russian Air Force. (Luftwehr, Vol. 5, No. 7, July, 1938, p. 279.) (59/5 Czechoslovakia.)

According to the Czech paper " Nenkow " the following table represents the present strength of the Russian Air Force:—

	Army
Fighters	1,792
Ground attack	390
Reconnaissance	2,300
Heavy Bombers	1,400
Light Bombers	900
Trainers	1,400
Total	8,182

Navy

Fighters	2,400
Battle planes	220
Reconnaissance	490
Heavy Bombers	104
Light Bombers	300
Trainers	696
Total	4,210

It is also claimed that during the first three months of the year 50 National Factories in the U.S.S.R. produced approximately 4,000 aircraft.

Conditions for the Successful Strategical Employment of an Air Force. (G. Kitcheeff, Rev. de l'Arm. de l'Air, No. 109, August, 1938, pp. 843-857.) (59/6 France.)

The successful strategical employment of an air force depends on the proper choice of targets. Since the depth of possible penetration by air is roughly of the order of 200 miles (unless the attacker has an overwhelming superiority) it is necessary for the aircraft to be stationed relatively close to the frontier, whilst the aircraft bases as such should be well to the rear. An ideal position for the attack occurs if both jumping-off aerodromes and supply bases can be arranged along circles surrounding the enemy. Interior lines of communication which were of definite advantage to the central powers in the world war thus lose their significance and may become even a source of danger in aerial warfare.

The possibility of forcing a quick decision may have tempted an aggressor State in the past to start a war. The author considers that with the advent of the air force the chances of ending a war quickly have become much more remote, unless one side or the other can establish from the start a clearly marked mastery of the air.

According to the author this entails at least a three-fold superiority in numbers, the aircraft material being equally efficient.

Fire Sectors on Aircraft. (P. Etienne, Rev. de l'Arm. de l'Air, No. 109, August, 1938, pp. 858-870.) (59/7 France.)

The author differentiates between two types of aircraft armament:—

(1) The guns are mounted in such a way that all the vital zones can be covered irrespective of the motion of the aircraft.

(2) Certain zones of fires can only be covered if the aircraft itself is properly orientated, *i.e.*, manœuvred into position.

Obviously, the amount of orientation possible differs according to whether the aircraft operates alone or in formation. In the latter case a sufficient degree of manœuvrability may generally be obtained by adopting the so-called "dynamic formation," in which only the leader follows a fixed course. In cases, however, where a fixed formation is considered essential, the necessary manœuvres may be carried out by mobile auxiliary aircraft accompanying the main squadron.

The author is of the opinion that the type of armament requiring a certain amount of orientation of the aircraft is preferable to the type in which the gun mountings are such as to enable all zones to be covered.

Flying Display at Touchino. (Les Ailes, No. 899, 8/9/38, p. 5.) (59/8 U.S.S.R.)

The display took place over the aerodrome of Touchino (near Moscow) on August 18th. The programme consisted of four parts:—

(1) Fly past of about 100 aircraft belonging to Ossoaviakhim (workers' flying clubs).

(2) Presentation of new civil and military types.
(3) Mock attack on ground targets placed on the aerodrome.
(4) Mass parachute jumps.

According to the French author, the display was much less interesting than that of last year. All the machines shown were several years old, with the exception of a six-seater transport, obviously inspired by the American Northrop.

The absence of new military types in the display may be accounted for by the military situation. A more probable explanation is the whole-sale " purging " of scientific staffs which is known to be taking place, and which must render new work practically impossible.

The Attack on Aerial Bases. (Rev. de l'Arm. de l'Air, No. 108, July, 1938, pp. 723-725.) (59/9 France.)

The war in Spain has shown that successful attacks on aerial bases are relatively rare. Yet bearing in mind the size of our own military aerodromes such attacks should be relatively easy, provided the bombers can get through.

Now the absence of highly organised signalling devices over the Spanish territory, together with the relatively small distances involved, should make interception a matter of difficulty. If attacks are nevertheless rare, the reason must be sought in the rudimentary nature of the bases, their small size and dispersion. Actual war conditions have demonstrated that the large aerodromes, comfortably fitted up, are unnecessary. Instead of a large flying field with a perfect surface, a single runway is provided and the machines are housed at some distance. The simple equipment makes frequent changes of locality possible, and it becomes a matter of difficulty to spot the actual position. Only low altitude bombardment can be effective and machines capable of carrying out this form of attack can ill be spared from the fighting front.

On the Stability of a Viscous Liquid between Rotating Co-axial Cylinders. (J. L. Synge, Proc. Roy. Soc., Series A, Vol. 167, No. 929, 5/8/38, pp. 250-256.) (59/10 Great Britain.)

The differential equations of the characteristic value problem for the small disturbance of a viscous liquid contained between two rotating co-axial cylinders are put into convenient form. From these is deduced an expression for the real part of the characteristic number occurring in an exponential time factor, the expression involving integrals in which the integrands contain the product of a characteristic function or one of its derivatives by the complex conjugate. If the circulation at the outer cylinder is greater than that at the inner cylinder and has the same sign ($w_2r_2^2 > w_1r_1^2 > 0$) the signs of these integrals are known without knowledge of the characteristic functions, and it is found that the steady motion is stable under the condition stated. Unlike the work of G. I. Taylor on this problem, the present theory involves no approximations based on the thinness of the layer of liquid, but (as in Taylor's work) the only disturbances considered are those which are independent of the azimuthal angle and periodic in the direction of the generations of the cylinders.

The Dornier Wind Tunnel. (H. Schlichting, L.F.F., Vol. 15, No. 3, 20/3/38, pp. 95-100. Available as Translation T.M. 868.) (59/11 Germany.)

After completion of the required calibrations, the Dornier open-throat tunnel is now in operation.

The following are the principal characteristics:—

Elliptic working section	3 × 4 m.
Length	7 m.
Max. air speed	60 m./sec.
Max. h.p.	800

The tunnel compares favourably with other installations (both German and foreign) as regards uniformity of velocity, static pressure and direction of air stream. The turbulence factor is low. The present equipment includes one three-component and one six-component balance.

Concerning Secondary Flow in Straight Pipes. (L. Howarth, Proc. Camb. Phil. Soc., Vol. 34, Part 3, July, 1938, pp. 335-44.) (59/12 Great Britain.)

The condition for the existence of a secondary flow in a straight non-circular pipe is determined according to the modified vorticity transfer theory, using Goldstein's assumed form for the tensor. It is shown that a secondary motion arises if the mixture length is not constant on the curves along which $|\operatorname{grad} u|$ is constant u being the velocity parallel to the axis of the pipe.

When turbulent flow problems are treated by this theory, the quantity $p+\frac{1}{2}\rho\overline{q'^2}$ plays a part analogous to that of pressure in laminar flow ($\overline{q'^2}$ being the mean value of the square of the velocity fluctuation and p the mean pressure). In two-dimensional flow through a channel the theory shows the existence of a gradient $p+\frac{1}{2}\rho\overline{q'^2}$ across the channel from the central plane to each wall. Qualitative arguments are employed to show that a secondary flow is to be expected near the short sides in the case of turbulent flow through a straight rectangular pipe of large length/breadth ratio.

Equations are given for the secondary flow through an almost circular elliptical pipe, the mixture length being assumed constant on ellipses similar to and concentric with the pipe section. As a first approximation the problem is reduced to the numerical solution of three simultaneous ordinary, linear differential equations.

Airfoil Theory for Non-Uniform Motion. (T. v. Kármán and W. R. Sears, J. Aer. Sci., Vol. 5, No. 10, August, 1938, pp. 379-90.) (59/13 U.S.A.)

The basic conceptions of the circulation theory of aerofoils are reviewed briefly, and the mechanism by which a " wake " of vorticity is produced by an aerofoil in non-uniform motion is pointed out.

The general results are applied first to the case of an oscillating aerofoil and then to the problem of a plane aerofoil entering a " sharp-edged " gust. In the latter case the rate of increase of the lift after the entrance of the aerofoil into the gust boundary is determined, and it is shown that during the entire process the lift acts at the quarter-chord point of the aerofoil.

The intention of the authors has been to make the aerofoil theory of non-uniform motion more accessible to engineers by showing the physical significance of the various steps of the mathematical deductions, and to present the results of the theory in a form suitable for immediate application to certain flutter and gust problems.

Investigation of a Flow of Compressible Gas in a Curved Channel. (V. G. Galperin, Trans. Centr. Hydrodyn. Inst., Moscow, No. 302, 1936, pp. 1-15.) (59/14 U.S.S.R.)

In a previous paper F. Frankl discussed a simple case of a curved channel in which the gas flow contains a supersonic region (velocity distribution being continuous). The form of the channel was obtained by approximate calculations based on existing theory. The present paper describes an experimental investigation of the above-mentioned channel. The data obtained show the presence of a supersonic region which undergoes transition into the subsonic one, not continuously, but in the form of shock waves. An attempt is made to explain this disagreement between theory and experiment.

Eddy Resistance of Theoretical Aerofoils. (A. Kosmodemiansky, Rept. Centr. Aero-Hydrodyn. Inst., Moscow, No. 317, 1937, pp. 1-58.) (59/15 U.S.S.R.)

The drag caused by break away of the flow on circular and elliptical cylinders and on symmetrical profiles is determined by means of Kármán's vortex streets. The calculation necessitates a knowledge of the breadth of the vortex street and of the intensity of the vortex. The author assumes that in the case of potential flow around a cylinder in a uniform flow parallel to its axis, the actual flow conditions shortly after break away of the first vortex can be represented with good approximation by means of two symmetrically placed vortices, at an as yet undetermined distance from the suction side. The position and intensity of the vortex are determined from the following conditions:—

1. Distance between the vortices (breadth of the vortex street) must be equal to the distance between the points of break away on the upper and lower sides of the body.

2. The velocity of the vortex at right angles to the direction of incident flow must be zero.

3. The points of break away corresponding to the theoretical flow as defined above must agree with those observed. For the sake of simplicity, the last condition is replaced by that stating that the pressure minima in the theoretical and actual flows must agree. Calculations are carried out for the laminar flow condition; the turbulent condition was investigated only in the case of a circular cylinder. Numerical values for the vortex drag are given only for the circular and the elliptical cylinder. Agreement between calculation and measurement is quite satisfactory.

On Some Reciprocal Relations in the Theory of Non-Stationary Flow. (I. E. Garrick, N.A.C.A. Report No. 629, 1938.) (59/16 U.S.A.)

In the theory of non-stationary flows about aerofoils, the lift functions, proposed by Wagner and Theodorsen, respectively, are of fundamental significance. This paper reports on some interesting relations of the nature of Fourier transformations that exist between these functions. General problems in transient flows about aerofoils may be given a unified broad treatment when these functions are employed. Certain approximate results also are reported which are of notable simplicity, and an analogy with transient electrical flows is drawn.

On the Stability of Vortex Sheets. (G. I. Petrov, Rept. Centr. Aero-Hydrodyn. Inst., Moscow, No. 304, 1937, pp. 1-23.) (59/17 U.S.S.R.)

By using the method of small vibrations the author first of all investigates the case of a plane, infinitely thin vortex sheet and finds that this is unstable under all kinds of disturbances. This result is then applied to the layer of separation of a circular jet. In this case an ideal fluid is assumed. When the vortex sheet is of finite thickness it is found to be unstable to disturbances above a certain wave length, but is stable to disturbances below this wave length. A disturbance wave length is found for which the amplification of the disturbance motion reaches a maximum value. Two plane parallel vortex sheets of finite thickness behave similarly so that they break away in a vortex sheet of unsymmetrical arrangement. The cylindrical circular ring vortex sheet also behaves in an analogous manner.

Wing Profiles under Conditions of Imperfect Lift. (F. Weinig, L.F.F., Vol. 15, No. 8, 20/8/38, pp. 383-391.) (59/18 Germany.)

The lift and moment of an aerofoil are materially affected by the position of the confluence point (juncture of air streams at the rear of the wing). The position of this point is affected by the Reynolds number, the degree of turbulence of the air stream, surface roughness and boundary layer control.

If the point of confluence lies exactly on the trailing edge of the wing, the lift is said to be perfect. The author shows that the moment of the air force is independent of the position of the point of confluence, provided the moment is referred to a special point, designated as the centre of the profile.

The moment can, therefore, be calculated if the lift is known, and vice versa.

Alternatively, knowing the lift, the position of the point of confluence and the pressure distribution along the profile surface can be calculated (except for the region in close proximity to the trailing edge).

Calculation of the Critical Velocity for the Two-Dimensional Case of an Aerofoil Fitted with Aileron. (G. Ellenberger, L.F.F., Vol. 15, No. 8, pp. 395-404.) (59/19 Germany.)

The object of this paper is to supply a simplified method suitable for preliminary investigations, damping being neglected. In an appendix, the author shows how aileron damping can be allowed for.

The principle of the method is similar to that first published by Kussner in 1929 (L.F.F. Vol. 4, No. 2, pp. 41/62). The author, however, introduces the aerodynamic force in a novel form, so that the effect of a variation in the relative chord ratio, *i.e.*, $\left\{\frac{\text{chord of aileron}}{\text{chord of complete wing}}\right\}$ can be readily investigated.

Propeller Efficiencies at High Flying Speeds. (G. Bock and R. Nikodemus, L.F.F., Vol. 15, No. 7, 6/7/38, pp. 334-339.) (59/20 Germany.)

The author shows that the possible efficiency of a propeller can be most suitably expressed in terms of two dimensionless factors. The first of these (so-called tip speed characteristic) combines the engine and propeller characteristics and is of the form

$$(n^2N/\rho)^{1/5}/V_R$$

whilst the second factor is the dimensionless flying speed V/V_R.

In the above

N = h.p. of engine.
n = r.p.m.
ρ = density.
V = flying speed.
V_R = resultant air speed at propeller tip.

It appears that propeller efficiency maxima occur at flying speeds of the order of 650 km./h. and that the efficiency diminishes rapidly for greater flying speeds. The rapid increase in rotary losses is mainly responsible for this decrease and it as yet impossible to state whether the difficulty could be overcome by fitting contrary rotating propellers or guide surfaces.

An increase in efficiency is theoretically possible if the tip speed characteristic is reduced below current values (large diameter propeller rotating very slowly).

It seems, however, that in this case the increase in weight of propeller and reduction gear will more than make up for any possible gain in efficiency.

Hydrodynamic and Aerodynamic Tests of Models of Floats for Single-Float Seaplanes. (J. B. Parkinson and R. O. House, N.A.C.A. Tech. Note No. 656.) (59/21 U.S.A.)

Tests were made in the N.A.C.A. tank and in the N.A.C.A. 7- by 10-foot wind tunnel of two models of transverse-step floats and three models of pointed-step floats considered to be suitable for use with single-float seaplanes. The models were designed at the N.A.C.A. tank as part of a programme having for its object the reduction of the water resistance and spray of single-float seaplanes without reducing the angle of dead rise believed to be necessary for the satisfactory absorption of the shock loads.

All the models were tested in the N.A.C.A. tank free to trim at one gross load. The results indicated that all the models have less resistance and spray than the model of the Mark V float and that the pointed-step floats are somewhat superior to the transverse-step floats in these respects.

The aerodynamic drag of the models was also determined in the N.A.C.A. 7- by 10-foot wind tunnel at angles of pitch from $-10°$ to $16°$.

Operating Characteristics of Large Flying Boats. (W. K. Ebel, J.S.A.E., Vol. 42, No. 8, August, 1938, pp. 7-12.) (59/22 U.S.A.)

The author discusses the operating characteristics of the present-day large flying boats and probable future trends as affected by the operating conditions, as compared with land transports. Among the various operating characteristics considered are water-handling (including spray formation and porpoising), flight characteristics, arrangement of crew and equipment, flying models, and seaworthiness. Of special interest is a discussion of the use of flying models, carrying pilot and observer, as an engineering tool to supplement wind-tunnel and towing-basin tests.

Theoretical Study of Various Aeroplane Motions after Initial Disturbance. (Fr. Haus, Bull. du Service Technique de l'Aeron., No. 17, June, 1937. Available as Translation T.M. 867.) (59/23 France.)

The study of the dynamic stability of aeroplanes by the method of small motions involves the determination of oscillatory and aperiodic motions. There are a great number of well-established methods for the calculation of the periods and the damping factors of these motions but which do not, in general, give any indication of the amplitudes of the motions set up. In the present paper the author, with the aid of a number of numerical examples, attempts to clarify the phenomena arising after a series of typical initial disturbances. It will be found that the results of these calculations contribute to an understanding of the mechanism of the motions which are set up, and it is hoped that the results, although limited to particular cases, will facilitate the study of the motions and flight paths. In the present study, the longitudinal and lateral motions are considered separately and the general theory is not considered.

Tank Tests to Show the Effect of Rivet Heads on the Water Performance of a Seaplane Float. (J. B. Parkinson, N.A.C.A. Tech. Note No. 657, July, 1938.) (59/24 U.S.A.)

A 1/3.5 full-size model of a seaplane float constructed from lines supplied by the Bureau of Aeronautics, Navy Department, was tested in the N.A.C.A. tank, first with smooth painted bottom surfaces and then with round-head rivets, plate laps, and keel plates fitted to simulate the actual bottom of a metal float. The percentage increase in water resistance caused by the added roughness was found to be from 5 to 20 per cent. at the hump speed and from 15 to 40 per cent. at high speeds. The effect of the roughness of the afterbody was found to be negligible except at high trims.

The model data were extrapolated to full size by the usual method that assumes the forces to vary according to Froude's law and, in the case of the smooth model, by a method of separation that takes into account the effect of scale on the frictional resistance. It was concluded that the effect of rivet heads on the take-off performance of a relatively high-powered float seaplane is of little consequence but that it may be of greater importance in the case of more moderately powered flying boats.

Wind Tunnel Tests of Three Lateral Control Devices in Combination with a Full-Span Slotted Flap on an N.A.C.A. 23,012 Airfoil. (C. J. Wenzinger and M. J. Bamber, N.A.C.A. Tech. Note, No. 659, Aug., 1938.) (59/25 U.S.A.)

A large-chord N.A.C.A. 23,012 aerofoil was tested in the closed throat 7- by 10-foot wind tunnel. The aerofoil extended completely across the test section, and two-dimensional flow was approximated. The model was fitted with a full-span slotted flap having a chord 25.66 per cent. of the aerofoil chord. The ailerons investigated extended over the entire span and each had a chord 10 per cent. of the aerofoil chord. The types of ailerons tested were: retractable ailerons, slot-lip ailerons using the lip of the slot for ailerons, and plain ailerons on the trailing edge of the slotted flap.

The data are presented in the form of curves of section lift, drag, and pitching-moment coefficients for the aerofoil with flap deflected but with ailerons neutral, and of rolling-moment, yawing-moment, and hinge-moment coefficients calculated for a rectangular wing of aspect ratio 6 with a semispan aileron and a full-span flap.

For the ailerons investigated the data indicate that, from considerations of rolling and yawing-moments produced and of stick forces desired, the retractable aileron is the most satisfactory means of lateral control for use with a full-span slotted flap.

Moments, Centrifugal Force and the Variable Pitch Propeller. (M. Baumann, Schweiz. Bauztg, 1938, Vol. III, pp. 113-117.) (59/26 Germany.)

Various types of variable pitch propellers are described and the problem of determining the balance weights for propellers of this type is discussed in detail.

Wind Tunnel Investigations of Aeroplane Spin, taking into Account the Radius of Rotation. (P. Jourachenko and E. Verjanskaya, Trans. Centr. Aero-Hydrodyn. Inst., Moscow, No. 260, pp. 1-74, 1936.) (59/27 U.S.S.R.)

The operating principle of the C.A.H.I. arrangement for investigations of spin depends on the simplifying assumption that the axis of spin passes through the centre of gravity of the aeroplane, consequently the radius of spin $r=O$. Experimental operation with values of r differing from zero leads to considerable complication of the apparatus and the technique of measurement (this has been done in a few foreign laboratories). As far as the calculation is concerned, the authors get round this difficulty by transforming and simplifying all the general equations of motion for spin, so that they obtain an easily applicable correction formula for $r \neq O$; thus the previous apparatus can still be used. It is shown that the correction factors for the aerodynamic forces and moments are nearly all unimportant. On the other hand the moments of the centrifugal forces require considerable correction. The present experiments are modified so that by means of special mass balance the inertia ellipsoid is converted into a sphere. The experiment thus only evaluates the aerodynamic effects. The rolling moment correction and the centrifugal force moments are then calculated. The method and scheme for calculation are illustrated by calculations for two types of aeroplanes.

Temperature Distribution on an Aircraft Wing: Application to the Problem of De-Icing. (E. Brun, Publ. Sci. Tech. Ministere de l'Air, No. 119, 1938, 47 pp.). (59/28 France.)

Contents. 1. Theoretical study of the distribution of temperature on a solid undergoing relative motion in a fluid. 2. Experimental arrangement for studying the distribution of temperature on an aeroplane wing. 3. Results of tests carried out on a model. 4. Results of tests carried out on a wing. 5. Applica-

tion of the temperature measurements made on the wing. 6. Note on ice formation on aircraft.

Ice can only commence to form on a wing at a temperature of less than or equal to o°C. Since the aeroplane is everywhere at a higher temperature than the atmosphere, the cloud must be at less than o°C. The thermal effects produced at the contact boundary between the wing and the air tend to oppose ice formation, since the temperature differences between different parts of the aeroplane and the air increase approximately as the square of the velocity, the frequency of ice formation should diminish in the future as speed increases. The best thermal-electrical method of preventing ice formation appears to be that of covering the external surface of the leading edge of the wing with a resistance. Ice formation is most likely to occur at air temperatures above $-8°$, *i.e.*, when the wing temperature is just below zero, hence the electrical power required to prevent ice formation will not be great. Formation of frost on the wing is accompanied by a rise in temperature which raises the deposit to o°C. A curve is given showing the energy in kilojoules necessary to remove ice.

Assumed Loads Due to Aerodynamic Forces on Aircraft. (G. Siegel, 173 pp., 1938, published by C. J. E. Volckmann, Berlin, Charlottenburg.) (59/29 Germany.)

Contents. I. Evaluation of Assumed Loads:—Effect of constructional data (flying weight, surface loading, span, profile, aircraft drag, airscrew thrust, dimensions of ailerons and landing flaps, shape of tail unit, etc.). Effect of performance data (highest horizontal dynamic head, diving flight dynamic head, diving from the serviceable ceiling height, rate of descent when landing).

II. Summary of the Necessary Data:—Evaluation of polars, longitudinal moment equilibrium, lift distributions, calculation of the maximum horizontal dynamic head in the neighbourhood of the ground, the dynamic head during diving and the rate of descent at 0.9Ca max.

III. Preliminary Discussion of Load Cases:—The fundamental load condition; load condition under the action of gusts and when using the ailerons, elevator or rudder; additional stress due to the airscrew; overlapping of the load conditions; unsymmetrical reduction of the air forces from one side; summary of all cases of loading.

IV. Calculation of Individual Important Cases of Loading.

V. Calculation of Loads on the Tail Unit.

Bibliography.

Floating Islands, Catapult Ships, Pick-a-Back Aircraft. (W. Zuerl, No. 25 of Handbooks for the Aircraft Constructor, published by C. Pechstein, Munich, 1938, 95 pp.) (59/30 Germany.)

The booklet is almost entirely devoted to aircraft catapults and descriptions are given of the four German Catapult ships Westfalen, Schwabenland, Ostmark and Fuesenland.

Effect of Shape of Wing on the Distribution of Load Along the Span and on the Longitudinal Stability. (A. B. Risberg, Rept. Centr. Aero-Hydrodyn. Inst., No. 335, 1937, pp. 1-80.) (59/31 U.S.S.R.)

Lift distribution is calculated for a wing of any shape, in particular for a trapeze wing, with and without a rectangular central section, by a method which is a modification of that proposed by Lotz. Instead of using the angle of incidence function $\alpha(\delta) \sin \delta$ and the chord function $\{ t_o/t(\delta) \} \sin \delta$ the functions $\alpha(\delta) \{ t(\delta)/t_o \} \sin \delta$ and $t(\delta)/t_o$ are developed. The chord function used by the author is often easier to expand than that of Lotz. The system of equations which is obtained for the unknown coefficients of the Fourier expansion for the circulation distribution, is not so sharply defined as in Lotz system; it can,

however, be solved by successive approximations. The author gives a complete explanation of the calculation for plane and twisted wings, with and without ailerons. The lift and moment coefficients for trapeze wings, with and without rectangular central sections, and of various aspect ratios and tapering are given in numerous diagrams. Comparisons are made between the calculated results and experimental results obtained by Wolkoff, Glass, Silman, Blenk and the Göttingen Research Institute. They show good agreement.

Wing Flutter when Taking into Account the Vibrations in the Direction of Greatest Stiffness. (P. M. Riz, Rep. Centr. Aero-Hydrodyn. Inst., Moscow, No. 340, 1937, pp. 1-20.) (59/32 U.S.S.R.)

When calculating the critical velocity it is usual to take into account only two degrees of freedom, namely, torsion and bending at right angles to the surface of the wing; the third degree of freedom, namely, bending in the direction of the wing surface, is neglected and the angle of incidence put equal to zero. Experiments carried out on a symmetrical streamlined strut showed that instead of it having the calculated critical velocity of 60 m./sec., flutter already occurred at a velocity of 8 m./sec. and at an angle of incidence below 7-8°. On increasing the angle of incidence, this flutter disappeared. In this case the vibration occurred noticeably in the direction of the greatest axis. This provided a reason for carrying out the calculation with all three degrees of freedom; this was done by Galerkin's method starting out from the steady air forces, with the result that at small angles of incidence the critical velocity came down to zero. Consequently in the case of very slim wings, particularly in presence of an airscrew, all three degrees of freedom must be taken into account.

On the Disturbed Motion of a Gas with a Boundary Layer. (D. Kuchemann, Z.A.M.M., Vol. 18, No. 4, 6/9/38, pp. 207-222.) (59/33 Germany.)

The two-dimensional motion of an inviscid compressible fluid is considered, the flow being parallel to a wall. The velocity is constant outside the boundary layer and decreases linearly inside the layer. If a small disturbing wave motion is superposed on the flow, two cases may arise:—

(1) For a set of characteristic discrete values of the wave velocity, the disturbance vanishes at infinity.

(2) Waves of finite amplitude at infinity may exist on the other hand for a continuous manifold of wave velocity values.

Typical flow diagrams are given by the author for both kinds of motion. In case 1, no trace of eventual turbulence could be detected. For case 2, the waves penetrate into the boundary layer and are reflected by it. The diagram shows in this case certain zones of return flow near the wall.

Measurement of Aileron and Flap Moments in Flight. (R. Schmidt, L.F.F., Vol. 15, No. 8, pp. 405-408.) (59/34 Germany.)

The force in the control lever is recorded by incorporating a special measuring device consisting of two tubes sliding one inside the other. The relative displacement of the tubes is controlled by a number of leaf springs arranged on a crosshead, the deflection being recorded by the D.V.L. scratch method. Knowing the force in the control rod, the couple follows at once from the dimensions of the lever system.

The results in flight differ appreciably from those obtained on a model in the wind tunnel. It appears that the air flow round the flap or aileron is not affected to a very marked extent by the presence of the wing if the width of slot is appreciable.

The flow is thus determined by the Reynolds number of the fitting (flap or aileron) rather than that of the complete wing.

To obtain reliable data thus may require models of relatively large size.

Surface Finish Related to Wear in Internal Combustion Engines. (K. W. Connor, J.S.A.E., Vol. 42, No. 8, August, 1928, Transactions pp. 305-12.) (59/35 U.S.A.)

Until recently, investigation of wear, lubrication, and maintenance of operating tolerances in internal combustion engines have been handicapped by the lack of factory type equipment which would permit standardised measurement in all conditions of manufacture and service.

The adoption of this combined new equipment indicates new opportunities for expansion of existing investigating technique; promises greater correlation of data on the causes of wear, and increased efficiency in production processing.

Cylinder Wear. (C. G. Williams, Autom. Eng., Vol. 28, No. 374, 17/8/38, pp. 289-294.) (59/36 Great Britain.)

The following are the main conclusions of the fourth Interim Report of the I.A.E. Research Committee:—

(1) Both cylinder and piston ring wear is reduced by increasing the width of the rings.

(2) Cylinder wear is principally due to the rings and the nature of the piston material (*i.e.*, cast iron or Al. alloy) has no effect, provided other factors such as ring groove clearance remain normal.

(3) The cylinder wear is the same for fresh or used oil.

(4) A chromium plated barrel with normal rings under intermittent operating conditions showed very marked reduction in cylinder and ring wear.

Continuous tests with chromium plated rings in a plain barrel also showed a considerable reduction in ring/cylinder wear.

Measurement of Mechanical Power. (C. V. Drysdale, Jun., Inst. Eng. Journal, Aug., 1938, pp. 499-531.) (59/37 Great Britain.)

Methods of mechanical power measurement are surveyed and it is concluded that there is a need for instruments and devices for measurement of engine power under operating conditions.

Brief descriptions are given of such instruments as belt dynamometers, pivoted electric generators (torque reaction) and torsion meters. Modern electrical devices are discussed with reference to an Air Ministry torsion meter based on the Ford induction meter, and a mechanical watt meter depending for its working on the voltage phase difference of two alternators mounted on the driving shaft. Suggestions are made regarding power measurement devices of low cost and small size, adaptable to motor vehicles.

Acoustic Vibrations and Internal Combustion Engine Performance, Part I, Standing Wave in the Intake Pipe System. (P. M. Morse, R. H. Boden and H. Schecter, J. Appl. Physics, Vol. 9, 1938, pp. 16-23.) (59/38 U.S.A.)

The vibration process in the intake pipe system of a single-cylinder four-stroke Otto engine has been investigated mathematically. The valve control produces stationary waves in the inlet pipe which can cause large pressure variations at the valve; these are considerably affected by the length of the pipe. The pressure variations at the inlet valve become greater if one of the harmonics of the engine speed should coincide with the national vibration frequency of the pipe or one of its harmonics. The equations of the vibration process are deduced for a simplified intake system. In particular, the conditions under which the vibration can produce additional charging of the working cylinder are indicated.

Testing of Hypoid Lubricants. (C. F. Prutton and A. O. Willey, J.S.A.E., Vol. 42, No. 8, August, 1938, pp. 325-34 (Transactions).) (59/39 U.S.A.)

A comparison is made of a number of test methods including: film-strength machine tests; various types of continuous-load tests; laboratory shock tests; and

road shock tests. This work has been in progress for more than fifteen months, has involved more than 50 lubricants, and more than 150 individual gear tests, each test requiring the use of a new set of gears.

The results of these tests indicate deficiencies in some of the lubricants under certain of the extreme conditions employed. Of the commercial lubricants studied, those that passed the laboratory shock test lubricate hypoids quite satisfactorily under practically all other test conditions where normal temperatures were used. The performance of the lubricants in the gear tests seems to bear but a slight relation to film-strength data as obtained on laboratory test machines.

Alternative Fuels—The Case for Vegetable Oils. (Autom. Eng., Vol. 28, No. 374, Aug., 1938, p. 298.) (59/40 Great Britain.)

The operation of transport Diesel engines on certain vegetable oils present no special difficulties apart from preheating the oil in order to reduce its viscosity. In general a reduction in power output of the order of 10 per cent. together with an increase in specific fuel consumption of the same order has to be reckoned with compared with standard oil.

Certain of the oils (ground nut and palm oil) are likely to have a corrosive effect on copper and iron, but it is thought that this is only a minor problem which could be overcome by the metallurgist once a demand for this type of fuel arises.

The high cost of these oils in England (£10-£20 a ton) rules them out for transport work, but different considerations apply in the east and in certain colonies where petroleum fuels are more expensive and the vegetable oils are produced locally.

For this reason the question is receiving the official attention of the French, Belgian and Italian governments.

Sensitivity of the Immersed Venturi Pitot Head at Low Speeds. (C. Salter, Phil. Mag., Vol. 26, No. 174, August, 1938, pp. 272-289.) (59/41 Great Britain.)

The simple venturi combined with a total head tube is not so convenient as the vane anemometer, but it can be made to give a pressure difference of many times that of the pitot static at speeds of the order of 10 feet/sec.

Unfortunately the immersed venturi is subject to a considerable scale effect at low Reynolds numbers and the performance of the instrument depends both on its overall size and shape.

The author carried out experiments with a series of venturis fitted with various inlet cones, the maximum diameter being app. 1in. and the overall length 4in. The wind speeds ranged from 0-10 feet/sec. For the best arrangement finally adopted, the sensitivity (at 10 feet/sec.) was app. 5 times that of the standard pitot static, falling off to 2½ times at air speeds of the order of 2½ feet/sec.

On account of difficulties in reproduction the author concludes that this type of instrument is not suitable to act as an accurate standard low speed anemometer, but that the information obtained during the course of the experiments may prove useful in low airspeed researches.

A Mechanical Optical High Speed Indicator. (S. G. Bauer, Engineer, Vol. 166, No. 4310, 19/8/38, pp. 196-198.) (59/42 Great Britain.)

The pressure element consists of a twisted steel tube at the end of which a stainless steel mirror is attached. Under the action of the gas pressure, the tube undergoes a further twist which is recorded optically on a rotating film. Such torsional movement cannot be induced by any ordinary engine vibration and the camera can thus be supported separately, which is the outstanding advantage of the instrument. T.D.C. or any other reference marks are marked by the discharge flash of a thyratron circuit, controlled by suitable contacts on the engine crankshaft. (Duration of flash $47.5 \times 10-6$ seconds.) For visual observation a

rotating mirror is provided which is driven at engine speed by means of a synchronous electric motor. The same drive also operates the film drum.

Sample diagrams obtained on an oil injection engine operating at 1,500 r.p.m. are given.

The natural frequency of the pressure element is stated to be 8,200/sec., and with the recording film at 1 m. from the mirror, 1 mm. deflection corresponds to a pressure change of approximately 18lb. per square inch.

Generalised Analysis of Experimental Observations in Problems of Elastic Stability. (E. E. Lundquist, N.A.C.A. Tech. Note No. 658, July, 1938.) (59/43 U.S.A.)

A generalised method of analysing experimental observations in problems of elastic stability is presented in which the initial readings of load and deflection may be taken at any load less than the critical load. This analysis is an extension of a method published by Southwell in 1932, in which it was assumed that the initial readings are taken at zero load.

Bending Stresses in Box Beams as Influenced by Shear Deformation. (P. Kuhn, J.S.A.E., Vol. 42, No. 8, August, 1938, Transactions, pp. 319-24.) (59/44 U.S.A.)

The problem of redistribution of bending stresses caused by shear deformation on the cover sheet, which cannot be avoided even in the most favourable cases, is considered as the most fundamental problem in box-beam design. Simplifying assumptions are discussed that permit a mathematical approach to the problem. Solutions for special cases finally are combined into a method of analysis intended chiefly for box-beam wings.

Analytical formulæ are given for a simple case. With the help of these formulæ, various structural arrangements of a small transport-size wing are compared. Numerical values are given for each case to show the error introduced by using the ordinary bending theory, and also to show how much extra weight is required to make up for the inefficiency caused by shear deformation.

Torsional Vibrations in In-Line Aircraft Engines. (R. M. Hazen and O. V. Montieth, J.S.A.E., Vol. 42, No. 8, August, 1938, Transactions, pp. 335-41.) (59/45 U.S.A.)

A discussion is presented of the two-node as well as the single-node characteristics for various crankshaft systems both with regard to frequency and to severity of vibration. The effect of frequency on harmonic torque input, which is a measure of vibration severity, is also discussed. The paper shows that, with a careful selection of the vibration frequency, the harmonic torque input for various vibration orders can be reduced considerably.

A method is presented for the selection rather than the determination of vibration frequencies. It is shown that, by the careful selection of frequencies, certain harmonic orders both for single-node and two-node vibration can be minimised appreciably and/or eliminated from the normal operating range of the engine. The friction type and the dynamic pendulum type vibration damper are discussed.

The stresses brought about by vibration must be considered before an intelligent restriction of vibration amplitude can be made.

The Torsion of a Two-Spar Pyramidal Wing with Closely Placed Ribs of Great Stiffness in Flexure. (G. S. Elenevsky and V. M. Darevsky, Rep. Centr. Aero-Hydrodyn. Inst., 1937, No. 292, pp. 1-43.) (59/46 U.S.S.R.)

A method is described for calculating the stresses in pyramidal, four-boom box spars, having isosceles, trapeze cross-sections, when fixed at one side and subjected to torsion. In the longitudinal direction there are assumed to be stiff ribs, placed infinitely close together, whose cross-section increases with the height

of the beam; the wall thickness of the skin is constant and the distribution of the torsion moment is assumed to be parabolic. The longitudinal stresses are taken only by the longitudinal stiffeners (constant shear-flow distribution in the individual walls). The unknown quantities are the bending moments acting in the separate walls and their magnitude are determined from the condition that the work done in producing change in shape is a minimum. It is shown that the distribution of the torsion moment in the individual walls in the rigidly held cross-section can be determined immediately from the conditions at the fixture and the equilibrium condition. In conclusion, the effect of the geometrical parameter and stiffness parameter on the values of the longitudinal stresses is discussed.

Method of Design and Experimental Investigation of Box Spars. (A. Romaszevsky, Rept. Centr. Aero-Hydrodyn. Inst., No. 310, pp. 1-88.) (59/47 U.S.S.R.)

Ebner's method (introduction of anti-symmetrical buckling force groups) for calculating thin-walled box spars under the action of torsion, with constrained cross-sectional buckling, is applied to cellular spars with reinforced corners and having walls which are rigid only towards tension. The transverse walls are taken to be rigid (differential equations with three terms). The box spar is also stressed for transverse-force bending. In this case the walls are again taken as stable to tension only; on the tension side, each half of the cross-section of the wall is combined with the adjoining corner stiffener. In order to test the theoretical calculations tests were carried out on box spars. The bad agreement between the calculated and measured shear flows is mainly due to the fact that in the experiment the shear flows were determined only from the tensile stress in the direction of folding, by assuming a uni-axial stress condition; this assumption is not justifiable when the buckling stress is slightly exceeded.

An Approximate Solution of Several Problems of Stability of a Cylindrical Shell. (N. V. Zvolinsky, Trans. Centr. Aero-Hydrodyn. Inst., Moscow, Rept. No. 246, pp. 1-56, 1926.) (59/48 U.S.S.R.)

The problem of the stability of a circular cylindrical shell under shearing stresses applied at the edge is considered. The problem is analysed by means of Love's differential equations, which have been simplified by the author, and is also solved by the Ritz method. A cylindrical shell bounded by two generators and circular cross-sections is considered. In addition, the problem of the torsional stability of a thin-walled cylindrical pipe is solved by the Ritz method. The results obtained are compared with the theoretical and experimental results of other authors.

Relief of Internal Stress in Castings. (L. E. Benson and H. Allison, Metro-Vick. Gazette, Aug., 1938, pp. 342-7.) (59/49 Great Britain.)

With the object of obtaining information on the removal of internal stresses in castings, experiments in annealing have been carried out at different temperatures. The experimental procedure is described and results are given for annealing and growth tests on cast iron. Similar annealing tests were carried out on steel, Admiralty gun-metal and high tensile bronze specimens; summarised results are given.

Chemical Treating of Surfaces. A New Principle in Lubrication. (A. L. Foster, National Petroleum News, Vol. 30, No. 26, 1938; J. Frank. Inst., Vol. 226, No. 2, August, 1938, pp. 245-6.) (59/50 U.S.A.)

The Feritex process consists in treating the steel surface of cylinder walls, rings, pins, crank bearings, etc., with a solution of certain chemicals for a given time at a given temperature, then cleaning the treated surface and oiling. The principle involved is that of selectively removing certain constituents from the steel

to a certain depth, forming a highly polished surface without irregularities, but one which is covered with a network of microscopic pits, grooves and slits while still preserving the even level of the main portion of the finished and polished surface. The lubricant is retained in the " hollows " and supports the working parts to a degree unknown except when using extreme pressure lubricants. The chemical solution—the composition of which has not been disclosed—does not affect the heat treatment or properties of the metal obtained by heat treatment, but merely attacks the surface without affecting tolerances or manufacturing limits set by the requirements of the product.

Dynamic Strength Properties of Light Metal Alloys at Low Temperatures. (K. Bungardt, Zeit. f. Metallkunde, Vol. 30, No. 7, July, 1938, pp. 235-7.) (59/51 Germany.)

The fatigue bending strengths of both aluminium and magnesium alloys increase with decreasing temperatures down to $-65°$; this is the case particularly for the aluminium—copper—magnesium alloys, the lowest alloyed Al-Mg alloy containing 4.68 per cent. Mg, and the Mg-Mn alloy. The effect of temperature on the fatigue bending strength was not so great in the case the Al-Mg alloys having greater Mg- contents, and the Mg-Al alloy.

The impact resistance of Al- alloys is increased by lowering the temperature to $-65°$, apart from the highest alloyed Al-Mg alloy containing 7.73 per cent. Mg, the impact resistance of which remained unchanged; in the case of Mg- alloys, the impact strengths decreased somewhat from low initial values as the temperature was lowered.

Fatigue Testing of Wing Beams by the Resonance Method. (W. M. Bleakney, N.A.C.A. Tech. Note No. 660, August, 1938.) (59/52 U.S.A.)

Preliminary fatigue tests on two aluminum-alloy-wing-beam specimens subjected to reversed axial loading are described. The method used consists in incorporating one or two reciprocating motors in a resonance system of which the specimen is the spring element. A description is given of the reciprocating motors, and of the method of assembling and adjusting the vibrating system.

The following are the principal conclusions:—

1. The reciprocating motor in conjunction with a resonant system is a convenient means of applying rapid axial load reversals to large specimens such as wing beams for fatigue measurements;

2. Specimens with local asymmetries in section, such as that portion of the front wing beam which includes the cabane-support attachment, may be loaded nearly uniformly;

3. The load may be applied directly to the specimen through a layer of Wood's metal without the necessity of " building up " the ends to prevent failure at the terminals;

4. The problem of determining the stress applied to the specimen is not a simple one but will require further development; and

5. The beams tested had no outstanding weak points in fatigue but rather exhibit approximately the same resistance to fatigue around the many rivet holes and other discontinuities distributed throughout their length.

The Determination of the Meteorological Conditions of the Atmosphere by the Use of Radio Sounding Balloons. (H. A. Thomas, Proc. Roy. Soc., Series A, Vol. 167, No. 929, 5/8/38, pp. 227-250.) (59/53 Great Britain.)

The essential features of an original method of exploration are described; in this method a signal of fixed radio frequency is employed and each meteorological instrument produces a continuous variation of modulation frequency. Calibration of the meteorological parameters in terms of frequency can be made independently of the radio transmitter, and measurement of these audio frequencies at the

receiver is comparatively easy. The pressure- and temperature-measuring instruments are both arranged to produce variation of modulation frequency without the use of mechanical linkages. The cost of the apparatus is comparatively low, and reproduction in large quantities is possible.

The results obtained from a number of experimental ascents are analysed and it is shown that a high degree of reliability and accuracy is obtainable. Using the present balloon, observation of both pressure and temperature up to an altitude of about 10 km. is obtained, the accuracy of the pressure and temperature determinations being about 5 mb. and 1°C. respectively.

The Measurement of Sand Storms. (R. A. Bagnold, Proc. Roy. Soc., Series A, Vol. 167, No. 929, 5/8/38, pp. 282-291.) (59/54 Great Britain.)

In a previous paper the author described wind tunnel experiments on the conditions of wind and ground surface governing the mass flow of sand across open country.

It was found that the vertical velocity distribution of the wind is profoundly modified by the presence of the loose sand.

Expressions were obtained both for this new gradient as well as for the mass flow.

In the present paper the author describes full scale experiments carried out in Egypt to test these formulæ.

Bearing in mind the difficulty of an exact comparison (different size of grain, dunes not flat, etc.), the agreement is satisfactory, the observed difference being accounted for by change in experimental conditions.

The Law of Error and the Combination of Observations. (H. Jeffreys, Phil. Trans. Roy. Soc., Series A, Vol. 237, No. 777, 14/4/38, pp. 231-71.) (59/55 Great Britain.)

The limitations of the theoretical grounds for accepting the normal law of errors of observation are discussed, and seven series of observations capable of providing tests of its truth are examined. It is found that the X^2 test, as usually employed, is not sufficiently sensitive to establish departures from the normal law. A wider grouping, however, reduces the random error of X^2 sufficiently to show the departures clearly, though it is still less sensitive than the ratio of the maximum likelihood solution for the departure to its standard error. It appears that no form of the test is of much use when the law to be tested implies very small expectations in some of the groups.

An approximation to the method of maximum likelihood for Pearson laws of Types II and VII is developed, and extensions to Types I and IV are suggested.

Methods of combining observations following such laws and determining their uncertainties are provided. It appears that a number of discrepancies in astronomy and physics that have been accepted as systematic may turn out to be random, since with such a law large random discrepancies may occur more often than with the normal law if the mean and the mean square deviation are still used as estimates.

An Electric Mechanical Method for Solving Equations. (A. H. Schooley, R.C.A. Review, Vol. 3, No. 1, July, 1938, pp. 86-96.) (59/56 U.S.A.)

An electro-mechanical method is described for finding the real and complex roots of high-degree algebraic equations having either real or complex coefficients. This method involves the adding (by series connection) of as many simultaneously variable voltages as there are terms in the equation. Each voltage is proportional to a particular term. The roots are found by adjusting the sum of the voltages to zero. Ways are described which will permit the rapid tracing of

equations in their real and complex planes. An experimental model has been constructed for solving cubic and lower-degree equations for their real roots.

Acoustical Insulation Afforded by Double Partitions Constructed from Dissimilar Components. (J. E. R. Constable, Phil. Mag., Vol. 26, No. 174, August, 1938, pp. 253-9.) (59/57 Great Britain.)

A theoretical investigation is made of the sound transmission through a double partition constructed from dissimilar components. It is shown that the insulation is to be expected to pass through a minimum as the separation between the components is increased, just as happens in the case of double partitions constructed from similar components. The sound reduction at the minimum increases as the dissimilarity between the components increases. On the other hand for a given separation the frequency at which the minimum occurs is smallest, and the minimum consequently, of least importance, when the components are similar. It is shown that at frequencies for which the resonances of the components and the air-coupling resonance can be neglected the insulation obtainable from a double partition of given total weight and thickness is greatest when the components are similar. It is concluded that double partitions are best constructed from similar components, and some experimental evidence in support of this is quoted.

Rapid Method for Obtaining Negatives in Aerial Photography. (A. Charriou and S. Vallette, Pub. Sci. Tech. Ministere de l'Air, B.S.T., No. 79, 1938.) (59/58 France.)

Two methods are available. The first is suitable for all photographic emulsions, developing being carried out in 25-40 seconds in a bath of the following composition:—

S.T.G.1	Genol	15 gr.
	Hydroquinone	15 gr.
	Anhydrous sodium sulphate ...	50 gr.
	Caustic soda	20 gr.
	Potassium bromide	1 gr.
	Water	1,000 ccs.

After being left in a 10 per cent. aqueous solution of acetic acid for a few seconds, fixing can be carried out in about 1 minute at 30°C. in a solution proposed by Lespert:—

Sodium hyposulphite	250 gr.
Liquid sodium bisulphite	25 ccs.
Ammonium chloride	60 gr.
Water	1,000 ccs.

Thus, when using normal photographic emulsions a negative is obtained in about 1½ minutes.

The second method can only be employed in case of specially sensitive layers, *i.e.*, consisting of a very insoluble emulsion in a thin layer (this type of emulsion is now in use commercially). Treatment is carried out at a temperature of 50°C. and developing takes only 10 seconds in the following bath:—

Genol	15 gr.
Hydroquinone	15 gr.
Anhydrous sodium sulphite ...	50 gr.
Caustic soda	10 gr.
Potassium bromide	8 gr.
Water	1,000 ccs.

A developed, fixed, rinsed and dried negative can be obtained in 50 seconds.

Styroflex and its Importance for Construction of Cables. (E. Fischer and F. H. Muller, Siemens Verofft Nachrichtentechn, 1938, No. 1, pp. 121-8.) (59/59 Germany.)

The electrical and chemical properties of polystyrene and of Styroflex are described; the latter is an excellent constructional material for cables since its dielectric constant is very low. It is unaffected by water and from the chemical point of view is completely stable. Styroflex is pliable and can be easily prepared in fibre- or band-form. The material has been tested in practice and satisfied all requirements with respect to mechanical strength and electrical properties.

Stability of Two-Metre Waves. (C. R. Burrows, A. Decino and L. E. Hunt, Bell Tele. Pubs., No. B-1077, 1938, pp. 1-13.) (59/60 U.S.A.)

By continuously recording a signal of 150 megacycles over a 60-kilometre path for a year, fading of up to 20 decibels has been found. This instability was most pronounced from sunset to a few hours after sunrise. The average field strength also tended to be higher during the night. A comparison of stability over various paths from 60 to over 200 kilometres has revealed similar diurnal characteristics. For a shorter path of 30 kilometres, fading was found to be considerably less than for the 60-kilometre path.

The fading magnitude was found to be approximately the same on several 60-kilometre paths differing widely in attenuation and including both optical and non-optical paths.

Because of the nature of the variations over this 60-kilometre path an increase of 7 decibels in power would have been required to maintain the field equal to or greater than the observed mean value 99 per cent. of the time.

LIST OF SELECTED TRANSLATIONS.

NOTE.—Applications for the supply of copies of translations mentioned below should be addressed to the Under-Secretary of State, Air Ministry (R.T.P.), Kingsway, W.C.2, and will be dealt with as far as availability of stocks permit.

Suggestions concerning new translations will be considered in relation to general interest and facilities available.

TRANSLATION NO. AND AUTHOR.	TITLE AND JOURNAL.
	AIRCRAFT (CONTROL).
670 Fuchs, D.	*Wind Tunnel Experiments on Aerodynamic Brakes.* (L.F.F., Vol. 15, Nos. 1-2, 20/1/38, pp. 19-27.)
674 Stuper, J.	*Effect of Slipstream on the Wing and Tail Unit.* (L.F.F., Vol. 15, No. 4, 6/4/38, pp. 181-205.)
680 Muttray, H.	*Experiments on the Downwash Behind a Trapezoidal Wing Fitted with Fuselage and Propeller.* (L.F.F., Vol. 15, No. 3, 20/3/38, pp. 101-22.)
683 Leiss, K.	*Mass Balance of Control Surfaces.* (L.F.F., Vol. 13, No. 12, 20/12/36, pp. 430-2.)
695 Ruden, P.	*Experiments with Slotted Wings.* (Jahrbuch der Deutschen Luftfahrtforschung, 1937, Vol. 1, pp. 75-86.)
	AIRCRAFT PERFORMANCE.
433 ———	*The Performance of Modern Long Range Seaplanes.* (Flugsport, Vol. 29, No. 3, 3/2/37, pp. 79-83.)
650 Hohenemser, K. ...	*Performance Possibilities of Rotary Wing Aircraft.* (Ingenieur-Archiv, Vol. 8, No. 6, Dec., 1937, pp. 433-49.)

TRANSLATION NO. AND AUTHOR.		TITLE AND JOURNAL.
691	Barth, W.	*The Rough Calculation of Flight Performance.* (Luftwissen, Vol. 5, No. 3, March, 1938, pp. 94-6.)

AIRCRAFT (DESIGN).

700	Lippisch, A.	*Results of Model Experiments with the Tailless Aircraft D.F.S.* 193. (Jahrbuch der Deutschen Luftfahrtforschung, 1937, Vol. 1, pp. 301-8.)
701	Seydel, E.	*A Basis for Comparing the Weight of Wing Structures.* (Jahrbuch der Deutschen Luftfahrtforschung, 1937, Vol. 1, pp. 371-6.)

AERODYNAMICS AND HYDRODYNAMICS.

145X	Schrenk, O.	*Wing with Boundary Layer Sucked Away.* (Luftfahrtforschung, Vol. 2, No. 2, 11/6/28.)
469	Frankl, F.	*Theory of Laminar Boundary Layer in Compressible Gases.* (Trans. C.A.H.I., No. 176, 1934, pp. 3-18.)
671	Cicala, P.	*Experiments on the Aerodynamic Forces Acting on an Oscillating Wing.* (L'Aerotecnica, Vol. 17, No. 12, Dec., 1937, pp. 1043-6.)

ENGINES AND ACCESSORIES.

483	Barth, W.	*Determination of the Resistance and Air Flow through Various "Cowled" Radiator Installations.* (Luftfahrtforschung, Vol. 14, No. 6, 20/6/37, pp. 300-3.)
491	von Philippovich, A....	*The Combustion Process in Explosion Engines.* (Zeit Elektrochem., Vol. 42, 1936, pp. 472-86.)
655	Skubatchevsky, G. ...	*Design of Supercharger Diffusors taking into Account the Friction Coefficients.* (Aeron. Eng., U.S.S.R., No. 9, Sept., 1937, pp. 52-67.)

MATERIALS AND ELASTICITY.

619	Geiger, J.	*The Stressing of Crankshafts.* (Autom. Tech. Zeit., Vol. 40, No. 4, 25/2/37, pp. 93-8.)
678	Ebner, H. ... ... Koller, H.	*Stress Distribution in Reinforced Cylindrical Shells.* (L.F.F., Vol. 14, No. 12, 20/12/37, pp. 607-26.)

INSTRUMENTS.

430	Myadzu, A.	*Influence of Type and Dimensions of Pressure Hole on the Recorded Static Pressure.* (Ing.-Arch., Vol. 7, No. 1, pp. 35-41.)
699	Janovsky, W. ...	*Telephonic Communication in the Presence of Noise and Wind.* (Siemens, Verofft, Geb. Nachrichtentech., Vol. 7, 1937, No. 5, pp. 873-8.)
707	Porro, General ...	*Photogrammetric Method for Determining the Speed of Aircraft and for Bombing Practice.* (Proc. of the International Congress on Photogrammetry, 1936, pp. 291-302.)

TRANSLATION NO. AND AUTHOR.		TITLE AND JOURNAL.
708	Vauzau, M.	*Photogrammetric Method of Determining Position and Plotting Path of an Aircraft in Flight.* (Proc. of the International Congress on Photogrammetry, 1936, pp. 247-80.)

ARMAMENTS.

546	Weiser, K.	*Calculation of the Lateral Deviation of Projectiles.* (Wehrtechn Monatshefte, Vol. 40, No. 5, May, 1936, pp. 225-35.)
702	———	*The Madsen Machine Gun for Aircraft.* (L'Aerophile, Vol. 43, No. 3, March, 1938, pp. 58-60.)

ABSTRACTS OF PATENT SPECIFICATIONS.

(Specially abstracted for the Journal by W. O. Manning, F.R.Ae.S.)

Abstracts of Patent Specifications received by the Society are published in the Journal. It should be noted that these abstracts are specially compiled by Mr. W. O. Manning, F.R.Ae.S., for the Journal and are only of those actually received and subsequently bound in volume form for reference in the library. These volumes extend from the earliest aeronautical patents to date, and form a unique collection of the efforts which have been made to conquer the air.

The Council accept no responsibility whatever for the accuracy of the abstracts and in any case of doubt the full patent can be consulted when necessary in the Library of the Society.

These abstracts are compiled by permission of the Controller of His Majesty's Stationary Office. Official Group Abridgments can be obtained from the Patent Office, 25, Southampton Buildings, London, W.C.2, either sheet by sheet as issued on payment of a subscription of 5s. per group volume or in bound volumes 2s. each, and copies of full specifications can be obtained from the same address, price 1s. each.

AERODYNAMICS.

488,942. *Improvements in or connected with Aerofoil Surfaces for Aircraft.* Vickers (Aviation), Ltd., and Ellis, D. L., both of Weybridge Works, Brooklands Road, Weybridge, Surrey. Dated Jan. 16th, 1937. No. 1,397.

It is proposed to use means for producing a suction on the under surface of an aerofoil and to communicate this suction to selected points on the upper portion of the aerofoil by means of a passage. It is claimed that the result is to modify the boundary layer flow so as to increase lift or reduce drag. The method proposed is to form a venturi passage under the aerofoil, possibly by using an auxiliary aerofoil spaced a short distance underneath it. The combination of the under surface of the main aerofoil and the upper surface of the auxiliary produces the desired venturi. The auxiliary aerofoil may be retracted into the main aerofoil.

484,405. *Improvements in Aircraft.* The Bristol Aeroplane Co., Ltd., Fedden, H. R., and Owner, F. M., all of Filton House, Bristol. Dated Nov. 2nd, 1936. No. 29,804.

Inside a body such as a wing forming part of an aircraft there is a chamber connected to perforations on the skin. There is also an ejector nozzle within the chamber, an exhaust pipe from the engine leading to the nozzle so that the ejector action of the exhaust gas draws air from the boundary layer along the conduit into the chamber, and discharges the air and gas rearwards.

483,561. *Control of Air Cooling Streams.* Cowdrey, C. L., 66, Long Hill Rise, Hucknall, Nottinghamshire, and Tate, J. W., 64, Long Hill Rise, Hucknall, Nottinghamshire. Dated Oct. 16th, 1936. No. 28,207.

It is proposed to control the airflow through a direct housing containing air cooling means by varying the size of the entrance to, or exit from, the duct by means of a member composed of flexible steel arranged at the entrance or exit

of the duct and forming part of the wall of the duct. Means are provided for bending it to varying extents.

AEROFOILS.

488,614. *Improvements in Aerofoils.* Ely, E. E., 4, Birkdale Road, Dewsbury, Yorks.; Ely, E. C., 45, Fairdale Gardens, Hayes, Middlesex; Ely, A. R., 4, Birkdale Road, Dewsbury, Yorks.; and Ely, D. G., 4, Birkdale Road, Dewsbury, Yorks. Dated Jan. 7th, 1937. No. 484.

The proposed aerofoil has a number of slots which project forward so that the opening on the top of the aerofoil is in front of the opening on the bottom. In flight it is stated that air passes from the upper to the lower surface of the aerofoil thereby breaking up any eddies or cushions of air on the upper surface of the wing.

489,853. *Improvements relating to Aerofoils.* Miles, F. G., Reading Aerodrome, Woodley, Reading, Berkshire. Dated Feb. 3rd, 1937, No. 3,229, and Dec. 9th, 1937, No. 34,147.

This is a flap gear, including at least two flaps which are adjacent, each flap being capable of angular movement relative to the wing and at least one having mechanism adapted to displace it to the rear. There is also claimed a combination of a split flap with an extensible flap whereby the area of the wing is virtually increased, having a slot between the wing and the flap. A number of flaps may be displaced rearwardly, simultaneously presenting slots between the flaps and the wing.

AIRCRAFT—CONSTRUCTION.

488,924. *Valves for Liquid Containers in Aircraft.* Ellor, J. E., Grandell, South Drive, Chain Lane, Mickleover, Derby, England. Dated Jan. 12th, 1937. No. 923.

This arrangement is intended for use in fuel tanks, etc., in aircraft where the tanks have branch pipes which unite in common outflow pipes and which are arranged so that during flight the contents of one tank might flow into the other. In order to prevent this each tank outlet is provided with a flap valve, the seat of which is inclined to the vertical. The arrangement is such that if flow from one to another tank is possible the appropriate flap valve shuts automatically so as to prevent it.

488,986. *Arrangements for Balancing the Torques Set Up in Rudders by the Action of Kinetic Forces.* Junkers Flugzeug-Und-Motorenwerke Aktiengesellschaft, 39, Junkersstrasse, Dessau, Anhalt, Germany. Convention date (Germany), March 1st, 1937.

It is proposed to attach a hinged member to the rudder which works in a chamber contained in the rear of the fin. The chamber is divided into two compartments by the hinged member, each compartment communicating with external space. The hinged member fixed to the rudder has a hinged auxiliary surface which is movably fixed in a fluid tight manner with one wall of the chamber.

488,105. *Improvements in Petrol Tanks.* Hall, F. H., Cleeve Cottage, Holford, Bridgwater, Somerset. Dated Dec. 31st, 1936. No. 35,784.

The proposed tank is arranged so that the fuel can be jettisoned quickly while the delivery of the fuel to the engine from this tank is interrupted, there being a reserve supply for the engine during interruption. A source of gaseous pressure is used which operates on the surface of the fuel and when this is turned on the air inlet is closed and the discharge syphon is automatically opened. The pressure required may be derived from any source of compressed gas or by means of an explosive cartridge.

487,404. *Improvements in and relating to Aircraft.* Nash, A. G. F., Oakcroft Road, Kingston By-Pass, Tolworth, Surrey. Dated Nov. 17th, 1936. No. 31,489.

This is an arrangement for reducing the resistance of an aircraft turret when the latter is extended, the fairing arrangement being movable and so arranged that it can cover the opening in the structure through which the turret is projected. The fairing is arranged to be brought within the space in the aircraft adjacent to the turret or below the skin of the aircraft when the turret is extended or projected.

487,548. *Improvements in or relating to Cockpit Covers for Use on Aircraft, Motor Boats and Ships and in Similar Positions.* The Fairey Aviation Co., Ltd., North Hyde Road, Hayes, Middlesex; Lobelle, M. J., Ludlow, 208, Langley Road, Langley, Bucks; and Trotter, J. C., 2, Manor Parade, Hillingdon, Middlesex. Dated July 1st, 1937. No. 18,323.

A vane is pivoted to the aircraft at what is normally its rear edge and is connected by a series of links and levers with the cockpit cover, the arrangement being such that when such flap or vane is opened from a forwardly directed position it becomes projected into the airstream. The air load acting on it tends to increase its opening movement and to balance the air forces on the cockpit cover which, owing to the link and levers, opens with the vane.

487,799. *Improvements in or relating to Aeroplanes.* Armstrong, J. J. V., 12, Church Street, Liverpool. Dated Dec. 24th, 1936. No. 35,459.

The proposed longeron consists of a core of wood tightly surrounded by a sheath of thin metal; means are provided to hold the core in endwise compression. Metal sheaths are formed by overlapping edges of sheet metal strips and welding. Bracing members are welded to the sheaths. Spars are formed by joining upper and lower longerons together by diagonal bracing.

483,085. *Improvements in or connected with the Construction of Wings, Surfaces and Fuselages for Aircraft.* Blackburn Aircraft, Ltd., and Petty, G. E., both of Seaplane Base, Brough, Hull, Yorkshire. Dated Oct. 12th, 1936. No. 27,626.

The proposed construction consists of using a number of tubular members running longitudinally through the wing or fuselage. These are of constant outside diameter but of varying gauge. These are spaced by transverse ribs or formers having a series of recesses round their borders which receive the tubular members. There is also an external cover of sheet material attached to the tubes.

483,302. *Improvements in and relating to Panel Securing Means in or for Aeroplanes and Vehicles with Sunshine Roofs or the Like.* Mobbs, R. O., United Building, Trading Estate, Slough, Buckinghamshire. Dated Aug. 14th, 1936. No. 22,449.

It is proposed to provide a simple means whereby sliding panels may be secured in any desired position. The retaining device proposed depends for its action on the flexibility of the hatch cover, and the device requires that the panel is flexed upwards whilst it is being moved and is engaged in position when it reaches the desired position by recovering its normal shape.

487,049. *A New and Improved Method of and Improvements in or connected with the Design and Construction of Folding Wings or Planes for Aircraft.* Hudson, R. J. H., Yennadon House, Dousland, South Devon. Dated Nov. 14th, 1936. No 31,126.

When wing folding is required to take place by rotations about two mutually inclined axes a wing is connected to the steel wing by means wholly within the thickness of the wing, comprising an element pivoted about a first axis carrying a

pivot joint of which the axis is substantially perpendicular to the first. There is a link to restrain the movement of the wing during folding. This member has for its function the constraining of the wing to move with a composite motion.

486,758. *A New and Improved Method of and Improvements in or Connected with the Design and Construction of Folding Wings or Planes for Aircraft.* Hudson, R. J. H., Yennadon House, Dousland, South Devon. Dated Oct. 9th, 1936. No. 27,388.

In folding wing aircraft in which folding is required to take place by rotation about two mutually inclined axes a wing is attached through connections comprising an element rotatably connected to the structure about a first axis and to the wing about a second axis intersecting the first at approximately a right angle. An external strut is pivoted to the aircraft about a third axis and pivoted to the wing about a fourth axis, the four axes being concurrent and the third axis lying in a plane to which the first axis is substantially perpendicular.

486,823. *Improvements in or relating to Aircraft Wings.* Dornier Metallbauten G.m.b.H., and Dr. Ing. H. C. C. Dornier, both of Friedrichshafen, Lake Constance, Germany. Convention date (Germany), Aug. 3rd, 1936.

The wing proposed consists of a main wing and a rigid or movable auxiliary wing the distance between them being a small fraction of the main wing chord. The trailing edge of the main wing and that of the auxiliary are each provided with one or more members extending over their length, which members are movable in an up or down direction. There may be more than one auxiliary wing.

486,849. *Improvements in and relating to Aircraft.* Lee, A., 851, Kingsway, East Didsbury, Manchester. Dated Nov. 3rd, 1936. No. 29,880.

The proposed aircraft wing has a series of impellers disposed in passages extending from the underside of the wing to the upper and adapted to be driven by the wind or by motive power. The axis of each set of impellers is at right angles to the longitudinal axis of the aircraft and is substantially horizontal, and is located at about one third of a chord from the leading edge. The diameter of the impellers may be reduced towards the wing tips.

486,067. *Improvements in or relating to Wind or Like Screens for the Cockpits of Aircraft, Motor Boats or Motor Cycle Sidecars, or for Use in Similar Situations.* The Fairey Aviation Co., Ltd., North Hyde Road, Hayes, Middlesex; Lobelle, M. J. O., Ludlow, 298, Langley Road, Langley, Bucks; Disch, A. G., 15, Melbourne Avenue, West Ealing, London, W.13; and Bolton, F., 22, Shanklin Road, Southampton, Hants. Dated July 1st, 1937. No. 18,322.

This specification is an addition to 427,226, and it is proposed that instead of the arched member being arranged to co-operate with the guides which extend horizontally forwards and then upwards and forwards, then upwards and rearwards, and then vertically upwards, it is pivotally connected at each side with a member slidable on a fixed vertical guide, mounted on the aircraft or the like, and with the upper end of a radius link, the lower end of which is pivoted to a fixed part of the aircraft.

485,324. *Method and Apparatus for Forming Aircraft Flotation Members from Fuel Tanks.* Walter Kidde and Co., Inc., 60, West Street, Bloomfield, New Jersey, U.S.A. Convention date (U.S.A.), April 15th, 1936.

A tank is proposed having a vent which conducts the fluid under pressure to means for closing the vent after said fluid under pressure has opened the discharge port. The fuel is evacuated so that the tank can be used as a flotation member.

The fluid under pressure may be introduced into the tank after it has opened the discharge port. Means are also provided for closing a vent in the tank and for closing the vent by the fluid under pressure.

484,305. *Improvements in or relating to Aircraft Wing Construction.* Beckay Aircraft Corporation, Ltd., and Hart-Still, S. C., both of 61, Crutched Friars, London, E.C.3. Dated Nov. 3rd, 1936. No. 29,909.

It is proposed to construct an aeroplane wing by a number of cells running spanwise formed by spars of vertical fly webs and flanges of the same material. These spars are reinforced throughout their lengths by beams secured to them.

484,622. *Improvements in or relating to Folding Wing Aircraft.* The Fairey Aviation Co., Ltd., North Hyde Road, Hayes, Middlesex; Lobelle, M. J. O., Ludlow, 298, Langley Road, Langley, Bucks; and Trotter, J. C., 2, Manor Parade, Hillingdon, Middlesex. Dated March 2nd, 1937. No. 6,210.

It is proposed that the wings of a low-winged monoplane shall be pivoted about vertical axes at the sides of the fuselage and between the leading and trailing edges while a part of the under side of the fuselage is retractable so as to allow parts of the wings when in their folded position to underlie the fuselage.

489,703. *Improvements relating to Cabin Tops, Cupolas and the Like for Aircraft.* Hawker Aircraft, Ltd., Canbury Park Road, Kingston-on-Thames, and Bower, C., of the Company's address. Dated May 15th, 1936. No. 13,855.

The cabin top proposed has a continuous covering of streamline form, and having a section rotatable out of continuity about the axis transverse to the length. A rear end section may be rotatable about a longitudinal axis, this being especially applicable when there is a rear gun mounting. The first rotatable section may be rotatable with a gun mounting so that it rotates turretwise and may be slotted so as to enable the gun to be elevated. The rear section rotatable horizontally has preferably a presto-conical section.

489,837. *Improvements relating to Cabin Tops and the Like for Aircraft.* Hawker Aircraft, Ltd., Canbury Park Road, Kingston-on-Thames, Surrey, and Bower, C., of the Company's address. Dated May 15th, 1936. No. 367.

The cabin top has a covering structure with a slidable door guided and supported on rails. The rails are displaceable transversely to their length, the door being thereby displaced transversely independently of its sliding motion. The door completes the streamline when closed and may have anti-friction rollers retained by a pair of parallel channel rails connected to the structure by parallel links.

490,151. *Improvements relating to Folding Wings for Aeroplanes.* Bagenische Flugzeugwerke A.G. Hannstetterstrabe 118a, Augsburg, Germany. Convention date (Germany), May 8th, 1936.

It is proposed to fold the wings of an aeroplane by arranging at a central position of the wing profile a joint movable about to angularly disposed pivoting axes. A brace is rotatively connected with a fixed point relative to the fuselage and to the foldable part of the wing. The path of the foldable portion of the wing may be so determined that the wing need not touch the ground, while the central position of the joint ensures that the wing need not be lifted. Hence it is claimed that the wing may be folded by one person.

490,031. *Improvements in and relating to Rubber and Metal Parts for Elastic Suspension Purposes.* Goldschmidt, M., Frankfurt, a.M., Germany. Convention date (Germany), Oct. 25th, 1935.

This proposal is concerned with an arrangement of rubber and metal parts in order to prevent vibration, especially for the suspension of aeroplane engines, the rubber being vulcanised to the metal. There is a number of concentrically bored out discs so arranged in two groups that in each case one of the discs mounted on the journal alternates with a disc fixed in the bearing, the rubber being vulcanised on between the discs.

AIRSCREWS.

488,455. *Paddle Wheel Propelling Means for Ships and the Like.* Mollica-Landi, A., Via F. Crispi 98, Naples, Italy. Dated July 7th, 1937. No. 18,856.

The proposed propeller has a rotating part provided with blades which are radially assembled on radial shafts on the body. These are controlled by spindles which can move axially forwards or backwards during the rotation of the body. On their forward stroke the spindles operate on the back of the blades so as to push them forward. As a result the blades are brought from a flat position on the body to a perpendicular position after which they gradually fall back to the flat position.

485,053. *Improvements in Mechanical Transmission Systems for Aircraft.* Almonacid, V. A., 105, Grande Rue, Boulogne-sur-Mer, Pas-de-Calais, France. Convention date (France), May 4th, 1937.

The proposed transmission system relates to a method of causing a rotating shaft to drive other rotating shafts located at a distance and parallel to the driving shaft. There are one or more driving shafts driving two or more driven propellor shafts, arranged so that the entire wing is subjected to the slip-stream of the propellors. The shafts have each at least two opposed cranks which are connected together by wires, rods, tubes, etc., so that the respective cranks are always parallel.

484,338. *Lifting Tackle for Airscrews.* Dorey, R. N., Grasmere, Burton Road, Findern, Derby, and Bellamy, R. A., 14, Stables Street, Derby. Dated Jan. 28th, 1937. No. 2,512.

The tackle proposed is attachable to a hoist-rope and also readily attachable to the airscrew, the two members being connected together by a member having a coarse thread by which one member can be caused to traverse with reference to the other, the effect being to vary the inclination of the airscrew. There may be a yoke member adapted to be clamped at each end to the root of one of the airscrew blades.

489,293. *Improvements in and relating to Propellers.* Duris, M., 9, Rue de la Mouilliere, Orleans, France. Convention date (France), Feb. 7th, 1936.

The propeller proposed has a rotor and a fixed portion, the former being mounted on the nose of the latter. The outer surfaces of each are formed as surfaces of revolution about a common axis, along which the device moves as a whole. The rotor has an annular rim which has a surface profile similar to that of the upper surface of an aerofoil with the leading edge pointing inwardly. Working fluid is caused to flow nearly parallel to the axis towards the centre of the rotor and thereafter radially and rearwardly over the annular rim and in an annular diverging stream, over the front portion of the nacelle.

490,747. *Improvements in or relating to Oppositely Rotating Co-Axial Propellers.* United Aircraft Corp., 400, South Main Street, East Hartford, Connecticut, U.S.A. Convention date (U.S.A.), Feb. 29th, 1936.

This specification describes an arrangement by which the co-axial propellers are driven by one engine at less than engine speed. The propellers have pitch changing mechanism. There is provided a pair of bevel gears and a number of pinion gears in a cage for rotating the sleeve, carrying one propeller in a direction opposite to the propeller shaft. There is also an axially movable sleeve disposed between the shaft and the sleeve connected to the propellers and capable of being controlled for the purpose of changing the propeller pitch.

AIRSHIPS.

487,906. *Airships.* Clark, F. B., 820, Connecticut Avenue, North West, Washington, Columbia, U.S.A. Dated April 6th, 1937. No. 9,826.

The proposed airship has a keel containing a cabin projecting from its underside and lying beyond the major curvature of the hull, the skin of the hull and keel being nearly continuous. The surface of the hull between it and the keel protrudes outward so as to provide an air tunnel on each side of the ship parallel with the longitudinal axis. Propellers are provided on each side and are arranged under the protruding portions of the hull.

487,639. *Improvements in Lighter-than-Air Aircraft.* Reichert, H. G., 2256, Lake Street, Salt Lake City, Utah, U.S.A. Dated Aug. 31st, 1937. No. 23,845.

The proposed airship has a number of individual cells each comprising a gas chamber bounded partly by a rigid wall and partly by a movable diaphragm, and means for moving the diaphragms to compress or expand the lifting gas to a pressure higher or lower than that of the surrounding atmosphere. The movable diaphragm divides the cell into a gas chamber and an air chamber and air can be blown into or exhausted from the air chamber so as to alter the pressure.

483,606. *Improvements in Airships.* Allen, A. W., 3307, North 16th Street, Philadelphia, Pennsylvania, U.S.A. Convention date (U.S.A.), April 21st, 1936.

This specification refers to the framework of airships of the Zeppelin type. In order to prevent the rigidity of the structure which is suggested is the cause of accidents, it is proposed to provide a framework which has a predetermined degree of flexibility. The proposed framework has a succession of rigid members flexibly connected together by means of resilient elements.

ARMAMENT.

485,750. *Towing and Dropping Bombs and Other Articles from Aircraft.* Castelli, J. L. A., 16, Rue des Sables, Viroflay (Seine et Oise), France, and Fremont, A. A., 3, Boulevard Julien Potin, Neuilly-sur-Seine (Seine), France. Dated Aug. 24th, 1938. No. 23,191.

There is a winding drum operated manually and fitted on the aircraft, a retractable towing device connected with the drum, a safety housing to be connected with the other end of the towing device and to be releasably engaged with the object to be towed and/or dropped. The body has stabilising fins for ensuring that it has a trajectory similar to said attacking or other carrying means.

490,028. *Improvements in and relating to Bomb Carrying and Dropping Apparatus for Use on Aircraft.* Short Bros. (Rochester and Bedford), Ltd., and Gouge, A., both of Seaplane Works, Rochester, Kent. Dated Oct. 12th, 1936. No. 27,627.

It is proposed to suspend the bombs in tiers between opposed guides which allow the bomb carriers to slide up and down and to drop completely out of the

guides. Means are provided for retaining the bombs in the stowed position and for releasing the bombs and the carriers when it is desired to drop them from the aircraft. Separation of the bomb from the carrier is automatically effected.

CATAPULTS.

489,417. *Improvements in or relating to Controlling Means for Aircraft Catapults.* Deutsche Werke Kiel Aktiengesellschaft, Werftstrasse 114, Kiel, Germany, and Hollmann, C., Gabelsbergerstrasse 28, Kiel, Germany. Dated Jan. 5th, 1938. No. 330.

The controlling means proposed has a piston operated by pressure, and a starting lever controlling the flow of air to the piston, the starting lever being automatically moved to its starting position after the movement has been initiated by hand. Accidents which might occur if the lever was not properly operated are thus avoided.

490,408. *Improvements in or relating to Apparatus for Aeroplane Launching.* Courtney, F. T., Sunray, Wroxham, Norfolk. Convention date (U.S.A.), Aug. 31st, 1936.

This is a type of launching catapult in which the aeroplane is carried on a special car which can be accelerated up to the flying speed of the aeroplane. The aeroplane support on the car can be swivelled laterally so that when starting the aeroplane can be pointed into the direction of the resultant wind. The support can be rocked fore and aft by the pilot so that the aircraft cannot take-off until full flying speed is attained. This action of changing the attitude of the aeroplane to take-off attitude may operate the releasing gear automatically.

490,214. *Launching and Landing Device for Aircraft.* Margeram, A. F., 48, Pullayns Avenue, East Ham, London, E.6. Dated Feb. 6th, 1937. No. 3,586.

It is proposed to launch the aircraft by means of an endless track. The aircraft is mounted on a carrier unit which rests on the endless track and which, after the track has gathered speed, is frictionally engaged with it so as to accelerate the aeroplane.

CONTROL OF AIRCRAFT.

488,967. *Improvements in or relating to Aircraft.* Pollopas Patents, Ltd., 2 and 3, Charterhouse Square, London, E.C.1. Dated July 2nd, 1937. No. 18,468.

This proposal concerns aircraft provided with a controlling and stabilising surface carried at a considerable distance above the wing of the machine. It is proposed that this surface shall consist of a number of independently adjustable elements mounted one behind the other in a fore and aft direction, the elements forming one unit in their zero position. The elements may also be arranged in the spanwise direction or the elements may be universally mounted, each being in the form of a unit.

483,497. *Improvements relating to the Control of Drag on the Outer Surfaces of Aircraft.* Fairey Aviation Co., Ltd., North Hyde Road, Hayes, Middlesex; Lobelle, M. J. O., Ludlow, 298, Langley Road, Langley, Bucks; Hooper, M. S., Pophley, Iver Lane, Iver, Bucks; and Morrey, P., Zosmor, 665, Great West Road, Osterley Park, Middlesex. Dated Oct. 22nd, 1936, No. 28,751; April 16th, 1937, No. 10,918; April 16th, 1937, No. 10,919.

The proposed wings are provided with apertures and means are provided for withdrawing air through said apertures. The apertures are arranged only over the trailing two-thirds of the top or corresponding surface of the body, and over

the trailing four-fifths of the bottom or corresponding surface thereof. The openings have forward projecting louvres, the length of the slits being from .025 upwards and the depth between .01in. to .04in.

484,693. *Improvements in or relating to Apparatus for Controlling the Tail Units of Aircraft.* Bleriot-Aeronautique Societe Anonyme, 167, Quai Gallieni, Surmesmes (Seine), France. Convention date (France), Aug. 5th, 1935. Specification not accepted.

It is proposed to provide a control system which permits of operating a V or similarly shaped tail unit by means of the same members as are usually employed for controlling an ordinary cruciform tail unit. Such members being a control stick and a foot bar or pedals for steering.

486,565. *Improved Mechanism for Actuating the Wing Flaps of Aircraft.* The Fairey Aviation Co., Ltd., North Hyde Road, Hayes, Middlesex, and Lobelle, M. J. O., Ludlow, 298, Langley Road, Langley, Bucks. Dated April 9th, 1937. No. 10,182.

The apparatus proposed consists of a link pivotally connected near the upper surface of the main wing and flap, and a lower link pivotally connected near the lower surface of the main wing and flap. Movement of the flap is effected by an hydraulic ram which is pivotally connected at one end with the main wing, and at the other end with the junction of the upper link and flap.

486,568. *Improvements in or relating to Controlling Devices for Aeroplanes.* Fairey, C. R., The Fairey Aviation Co., Ltd., North Hyde Road, Hayes, Middlesex. Dated June 5th, 1937. No. 15,656.

In this specification the trailing edge of the wing is split into an upper and lower section, the upper section being connected with the lower by a link, the connection with the upper section being behind the connection with the lower. These connections are to be near the centres of pressure of the two sections.

486,682. *Improvements in or relating to Control Apparatus especially for Aircraft.* The Fairey Aviation Co., Ltd., North Hyde Road, Hayes, Middlesex; Roberts, H. F., 21, Glebe Road, Hayes; and Venning, W. H., 24, Argyll Avenue, Southall, Middlesex. Dated Feb. 13th, 1937. No. 4,387.

This device relates to a method of registering the degree of rotation of a control device such that several such devices may be combined in a compact structure. Each such control device is provided with an involute spiral form on a wheel and a pivoted arm, one end of the arm forming a pointer co-operating with a fixed scale and the other end of the arm engaging with the spiral groove.

486,749. *Improvements relating to the Operation of Control Surfaces of Aircraft.* Hudson, R. J. H., Yennadon, House, Dousland, South Devon. Dated Dec. 8th, 1936. No. 9,608.

The control mechanism consists of a spindle rotatable about a first axis carrying a pivot joint with an axis substantially perpendicular to the first, these two axes intersecting at the hinge of the surface at a point. The pivot joint is a connection with a further rotatable element which can rotate in the surface and which intersects at the said point and which is inclined to the first and third axes.

485,794. *Improvements in or relating to Aircraft.* Back, W. E., Mancroft Towers, Oulton Broad, Suffolk. Dated March 4th, 1937. No. 6,479.

The proposed aeroplane has ailerons and a control member by which the ailerons can be moved differentially for banking and which when moved fore and aft moves the ailerons in the same direction and simultaneously moves a tail elevator in

the opposite direction. There is a separate control member so that the aileron can be moved together or to cause the ailerons to act as a brake without moving the elevator appreciably.

485,069. *Landing Flaps on Aircraft.* Deutsche Versuchsanstalt fur Luftfahrt, E. V., Rudower Chausee 16/25, Berlin-Aldershof, Germany. Convention date (Germany), July 27th, 1936.

The proposed flaps are stated to avoid disturbance of the stability and trim of the aircraft when they are deflected. They are slot flaps with a chord dimension of from 50 to 60 per cent. of the wing profile, the slot being closed in the neutral position.

486,954. *Improvements in Means for Laterally Controlling Aircraft.* Blackburn Aircraft, Ltd., and Fenton, G. B., both of Seaplane Base, Brough, nr. Hull, East Yorks. Dated Nov. 11th, 1936. No. 30,776.

There is a main flap on the wings at each side of the aircraft, upper and lower subsidiary flaps on each main flap which can be raised and lowered with respect to the main flap; means for operating the subsidiary flaps independently of the main flaps so as to raise the upper flap on one side and lower the lower one on the other while the remaining flaps remain against the main flaps.

489,771. *Improvements relating to Fluid-Pressure Jacks, Particularly for Air craft Flap or Like Control.* Miles, F. G., Reading Aerodrome, Woodley, Reading, Berkshire. Dated Feb. 3rd, 1937. No. 3,228.

The proposed fluid pressure jack has two cylinders in a single body each with a piston, the pistons extending oppositely and having differing strokes. The body is movable, rotating to the points of attachment. The points are part of the wing structure and part of a wing flap, etc., and the jack can be used for two or three differing stroke lengths by selecting how pressure is supplied, either to one cylinder or both. The cylinders are preferably in tandem and double acting.

490,419. *Improvements in or relating to Aeroplane Wing Flaps and Multi-Position Actuating Mechanism Therefor.* United Aircraft Corporation, 400, South Main Street, East Hartford, Connecticut, U.S.A. Convention date (U.S.A.), Feb. 15th, 1936.

The wing flap is moved to various positions for increasing lift and is maintained in such positions by means of a hydraulic ram, having an outlet and a number of inlets corresponding to the various desired positions of the flap. There is a pump for supplying pressure and a manual means for controlling it and manual means for selectively opening the desired one of the inlet openings.

489,392. *Improved Method and Means for Operating Trimming or Balancing Flaps on the Control Surfaces of Aircraft.* Boulton, Paul Aircraft, Ltd., The Airport, Wolverhampton, and Clark, W. H. V., Westholme, Wood Road, Codsall, near Wolverhampton. Dated 25th Feb., 1937. No. 5,634.

The proposed trimming tab is operated through a lever fixed inside the frame of the control surface so as to control the rotation of the tab about its hinges. The lever is itself coupled to a member attached to a fixed part of the aircraft, the point of connection being near the axis about which the control surface is hinged. The degree of movement of the tab can be determined by moving this point of connection.

CONTROLS.

485,467. *Improvements in and relating to Liquid Pressure Remote Control Systems.* Automotive Products Co., Ltd., Brook House, Langham Street, London, W.1, and Parker, S. M., of the same address. Dated Nov. 17th, 1936. No. 31,469.

This is a double acting liquid pressure remote control system having a number of slave cylinder units fed from a common source of pressure through either one of two pipe lines. The slave cylinders are arranged to effect a number of operations in a predetermined sequence when pressure is fed through one pipe line and in the reverse sequence when pressure is fed through the other pipe line.

DE-ICING.

488,820. *Improvements relating to Anti-Icing Devices for Aircraft.* Rideau, J. R., 33, Rue Greuze, Paris, France, and Ducrat, A. M., 11 bis, Rue des Acacias, Paris, France. Convention dates (France), Nov. 6th, 1936; April 30th, 1937; and Oct. 21st, 1927.

The scheme proposed is to mount on the parts of the aircraft which require protection a superficial electrically conducting covering from which heat is evolved by the passage of an electric current; the covering may consist of bands of metal deposited by spraying. The covering may be supported by a sheet of asbestos which may be applied to a covering of cork. Again, the covering may consist of finely divided carbon deposited from a colloidal suspension or of a fine wire mesh or of a thin metal sheet.

486,549. *A New and Improved Apparatus for Preventing Ice Formation on Aircraft Surfaces.* Headen, L. A., St. Mary's Works, Frimley Road, Camberley, Surrey. Dated Dec. 7th, 1936. No. 33,503.

The method proposed consists of providing an air heater on the engine, heated air from which is forced by a blower into a tube located in the leading edge. This tube has apertures so situated that the heated air is directed to impinge in jets against the interior of the leading edge.

486-891. *Automatic Control Means for De-Icing Mechanisms for Aircraft.* Eclipse Aviation Corporation, 545, North Arlington Avenue, East Orange, New Jersey, U.S.A. Convention date (U.S.A.), Dec. 14th, 1935.

The de-icing device consists of a member attached to the aircraft surface which can be agitated, including inflatable members: Means are provided for periodically inflating such inflatable members and means are provided for automatically controlling inflatable means. The automatic control consists of a paddle mounted in a tube fixed to the aircraft so that when the aircraft is in flight the paddle is forced backwards. In front of the tube there is a gauge which becomes coated with ice under ice-forming conditions. This stops the air supply to the paddle which then moves forward under the action of a spring. In doing so it makes an electric contact and sets the de-icing mechanism into action.

485,395. *Means for Preventing the Formation of Ice on the Wings and/or Fuselage of Aircraft.* Brookfield, J. C., Floreat, Copsom Drive, Esher, Surrey. Dated Dec. 3rd, 1936. No. 33,165.

A heat radiating pipe carrying exhaust gas is carried along the wings or fuselage immediately behind the leading edge. There is an internal partition which, in conjunction with the surface of the wing or fuselage, forms a hot air chamber through which the pipe is led. This portion is made of, or impregnated with, a heat conducting material which is exposed on one side to the hot air chamber and on the other to the atmosphere.

ENGINES.

487,677. *Improvements in or relating to the Remote Control of Aircraft Engines.* Dumax, G. C., 15, Rue de la France-Mutualiste, Boulogne-sur-Seine (Seine), France. Convention date (France), Dec. 23rd, 1935.

The operating member is connected by a sheathed cable to a distributing member which is, itself, connected by distant drives to a number of control devices consisting of fuel and lubricating oil cocks and the earthing switches of the engine magnetos. The operating member consisting of a lever provided with a toothed sector that engages with a rack which is attached to one end of the cable. The distributing member has a number of cams serving as a track for a roller pusher, the rod of which is connected to one end of a drive. Cams are provided on which the earthing contacts of the magnetos bear.

486,759. *Improvements in Aircraft.* The Bristol Aeroplane Co., Ltd., and Radcliffe, J. M., both of Filton House, Bristol. Dated Nov. 2nd, 1936. No. 29,805.

It is proposed to supercharge an engine by heating the charge, by compressing it to a pressure greater than that at which it would be fed to the engine, cooling it, and expanding it after it leaves the cooler to the desired supercharger pressure so as to reduce its temperature still further. Air drain from underneath the wing passes through a compressor and a cooler. It is then discharged into a duct which takes air from the top of the plane to the carburettor, the discharge taking place so as to accelerate the air in this duct towards the carburettor.

484,300. *Control of Cooling Air Stream of Aircraft Engines.* Ellor, J. E., Grandell, South Drive, Chain Lane, Mickleover, Derby, England. Dated Sept 30th. No. 26,567.

The radiator is housed in a tunnel or duct at the exit of which there is a flap mechanism which is balanced aerodynamically as nearly as possible. The size of the exit is controlled by one or more vanes or flaps of streamline section each hinged transversely, the axis passing through or close to the aerodynamical centre. The flap can be moved so as to more or less obstruct the flow.

489,594. *Improvements in or relating to Cowlings for Aircraft Engines or Radiators.* Mercier, P. E., 11, Rue Jacques Dulud, a Neuilly-sur-Seine (Seine), France. Convention dates (France), Aug. 26th, 1937; Oct. 19th, 1937.

It is proposed that the inlet and outlet of the cooling air entering a cowling should be simultaneously controlled. At the entry there is at least one annular element so that there are two concentric inlets. The annular elements can be axially displaced, altering the area for the entry of air. If more than one annular element is used different elements may move in opposite directions.

489,076. *Improvements in or relating to the Air Cooling of the Cylinders of Internal Combustion Engines on Aircraft.* Mercier, P. E., 11, Rue Jacques Dulud, a Neuilly-sur-Seine (Seine), France. Convention dates (France), March 10th, 1937; April 16th, 1937; July 29th, 1937; Aug. 9th, 1937.

It is proposed to furnish air-cooled engine cylinders with hollow fairings forming deflectors, each of which divides the in-coming air into two sheets which flow towards the two sides of the cylinder, the air being guided by the surface of the fairing adjacent to the cylinder which fairing is so shaped as to cause the air to traverse the gills and to flow out through the flue-like interior of the hollow fairing.

FLYING BOATS.

483,423. *Improvements in or connected with Flying Boats.* Short Bros. (Rochester and Bedford), Ltd., and Gouge, A., both of Seaplane Works, Rochester, Kent. Dated April 23rd, 1937. No. 11,644.

This specification refers to the detailed structures of flying boat hulls and claims a hull comprising cross frames composed of floor members with flanges and webs and inclined bottom members with flanges and webs, said members having flanges disposed outwards convected by bracing members longitudinal members and webs extending continuously across the cross frame, means for attaching the webs of the longitudinal members up to the flanges of the inclined bottom members and bottom plating supported by the flanges of the longitudinal members.

INSTRUMENTS.

487,010. *Improvements in Means and Method of Instrument Indication in Aeroplanes and the Like.* Link, E. A., Binghampton, Broome, New York, U.S.A. Dated Aug. 26th, 1937.

It is proposed to project optically the images of aircraft instruments on to a screen so as to provide a single group of these images. They may be grouped differently from the grouping of the instruments and those having similar movement characteristics may be correlated in vertical and horizontal planes. These images may be closer together than the instruments themselves and the images may be projected with the aid of prisms and optical lenses.

487,755. *Improvements in or relating to Indicating Instruments for Aircraft.* Siemens Apparati und Maschinen Gesellschaft mit beschrankter Haftung, Askanischer Platz 4, Berlin, S.W.11, Germany. Convention date (Germany), Dec. 12th, 1936.

This is an indicating instrument for retractable undercarriages comprising two electrical measuring instruments, the pointers of which represent, and are controlled by, the movement of the supports of the landing wheels. The pointers are vertical when the wheels are in the position for landing. The pointers are concealed behind the lower edge of a diaphragm of an aeroplane when the aeroplane is in the flying position. Pointers for a foldable tail skid or wheel and for landing flaps may be added.

MISCELLANEOUS.

489,001. *Movable Apparatus for Lifting and Manipulation of Loads.* Kervarree, B., 3, Rue de Villejust, Paris, France. Convention date (France), Jan. 15th, 1936.

This proposal relates to derricks intended to be mounted on ships for the repair of seaplanes. The derrick has two or more cables serving for translatory motion and for supporting the jib. The cables are attached, one at platform level and the other at the height of the derrick so that the translation of the derrick is obtained by winding the said cables over winches mounted on the derrick or its carriage. The displacement of the derrick occurs with a nearly constant inclination of the jib. The apparatus may be operated with compressed air.

484,657. *Improvements in or relating to Means for Coupling or Uncoupling Aircraft during Flight for Landing or Launching.* Plesman, A., Hofweg, 9, The Hague, the Netherlands. Dated Jan. 11th, 1937. No. 3,045.

In connection with aircraft without landing gear by attaching auxiliary aircraft with landing gear during flight a method is described for permitting coupling and uncoupling. The auxiliary aircraft is provided with cup-shaped surfaces adapted to engage with corresponding parts in the shape of a segment of a sphere on the main aircraft. Each surface may be mounted on the top of a column while means

may be provided for catching one or more cables lowered from the main aircraft and means for coupling the auxiliary aircraft with the cables, and for drawing both aircraft together by the cables.

485,599. *Improvements connected with Advertising or like Appliances for Aircraft.* Airwork, Ltd., Heston Airport, Hounslow, Middlesex, and Addwell, H., of the same address. Dated Dec. 1st, 1936. No. 32,885.

The banner carrying roller is supported in a frame which is movable to bring the roller into or out of the banner displaying position. It is also retractable within the fuselage so that the banner may be changed. The framework supporting the roller is tiltable beyond the vertical so that the axis of the roller may be brought perpendicular to the centre line of the banner so as to facilitate winding.

486,983. *Improvements in Draining and Ventilating Eyelets.* Woods, L. R., 6, Milk Street, London, E.C.3. Dated Feb. 25th, 1937. No. 5,685.

The proposed eyelet consists of a plate with a median opening covered by a hood forming a dishing of the plate, the hood having an aperture. The hood may be of a streamline shape and its aperture may be of the form of a slot.

487,540. *Process for Manufacturing Hollow Bodies and Products Resulting from this Process.* Duverne, G., 33, Rue Mathurin Regnier, Paris (Seine), France. Convention date (France), May 15th, 1936.

It is proposed to form a hollow body of wood, etc., by forming a mould including parallel spaced transverse flat pieces having contours corresponding to those of the body to be formed and bending on this mould separable halves of the body to be formed, removing the halves from the mould and uniting them together along their corresponding edges.

486,556. *Improvements in or relating to the Braking and/or Mooring of Aircraft.* Sir George Godfrey and Partners, Ltd., and Theed, W. D. L., both of 466, Edgware Road, London, W.2. Dated Dec. 7th, 1936. No. 33,557.

It is proposed to provide the aircraft with an electro-magnet which can be energised by a current supply on the aircraft, the switch being under the control of the pilot. This magnet can be lowered by the pilot until it is in contact with the aerodrome. The aerodrome surface is composed partly of magnetic material.

486,441. *Improvements in and relating to Aerial Posters.* Air Publicity, Ltd., Phillips, P., and Tucker, S. A., all of 11, Buckingham Street, London, W.C.2. Dated Dec. 2nd, 1936. No. 33,071.

The poster is wound up round a post or roller and when it is desired to display it the post is projected below the aeroplane and the poster unwound. Several of these may be carried on the same aeroplane and they may be changed in flight, a poster being withdrawn by being rewound on the post and returned to the aeroplane.

485,415. *Improvements in and relating to Aerial Posters.* Air Publicity, Ltd., and Phillips, P., both of 11, Buckingham Street, Strand, London, W.C.2. Dated April 20th, 1937. No. 11,244.

An arrangement is proposed by which the poster can be canted towards the position in which it is to be read by means of a fin or vane. This vane is attached to the front vertical strut of the poster so as to co-operate with the slip-stream of the aircraft to urge the bottom of the poster away from the direction of reading, *i.e.*, the direction in which the letters face, or alternating to urge the upper portion of the strut inwardly towards the direction of reading.

489,139. *Improvements in or relating to Wind-Driven Power Apparatus.* Dr.-ing. A. van Gries, 72, Aussbaumerstrasse, Koln, Germany. Dated July 27th, 1937. No. 20,813.

It is stated that wind-driven dynamos adapted to be lifted by captive balloons or kites have been proposed, the difficulty being the weight to be lifted. In order to get over this difficulty it is proposed to use a number of interconnected kites, by which method, it is claimed, the lift can be increased indefinitely.

489,931. *Improvements in and relating to Means for Testing Shuttlecocks.* Miéville, A. L., Cudlow House, Rustington, Sussex, and Slazengers, Ltd., Laurence Pountney Hill, Cannon Street, London, E.C.4. Dated Dec. 5th, 1936. No. 33,439.

The shuttlecocks are introduced into a chamber which is provided with an adjustable flow of air. As a result of the tests carried out in this chamber it is claimed that the flight characteristics of the shuttlecock can be ascertained without damage to the specimen tested.

MODEL AIRCRAFT.

488,585. *Improvements in Toy Aeroplanes.* Lines Bros, Ltd., and Wilmot, C. M., Tri-ang Works, Morden Road, Merton, London, S.W.19. Dated Jan. 16th, 1937. No. 1,408.

It is proposed to emboss thin material such as paper into the shape of half a fuselage, so that when two such pieces are stuck together a tubular fuselage is produced. The paper may be printed before embossing and apertures may be formed in it so as to attach plane, tailplane, etc.

487,616. *Automatic Flying Control for Model Aeroplanes.* Button, H. C., Field View, Wrenbury, Nantwich, Cheshire. Dated Feb. 23rd, 1937. No. 5,342.

The proposed automatic control consists of a tiltable tube arranged longitudinally in the aeroplane and containing a movable mass or weighted body such as mercury or a heavy ball which can move from end to end of the tube. The tilting of the tube is limited and it actuates through connections the elevators or, if desired, the flaps so as to control automatically the flight of the aeroplane.

486,396. *Improvements in Toy Aircraft.* The Lionel Corporation, 15, East 26th Street, City, County and State of New York, U.S.A. Convention date (U.S.A.), Jan. 4th, 1937.

The proposed toy aircraft is tethered to a stationary support and has a stationary electric motor actuating an airscrew to cause the aircraft to rotate about the support. The speed of the aircraft is controlled mechanically and the aircraft can be made to climb, dip, loop, etc.

484,303. *Improvements relating to Toy Aeroplanes.* Hammer, W. H., 631, Wilshire Boulevard, and Rhodes, L., of 1332, 15th Street, both in Santa Monica, California, U.S.A. Convention dates (U.S.A.), Nov. 4th, 1938, and Feb. 10th, 1936.

The proposed toy aeroplane is constrained to move about a centre and has a motor from which power is transmitted to the propeller. The aeroplane structure can be made to rotate tail over nose or nose over tail in a controlled fashion and the aeroplane may be caused to dip, rise or loop.

PARACHUTES.

488,774. *Improvements in or relating to Parachutes.* Willing, M. S., Bushfield Farm, Mount Holly, West Moreland, Virginia, U.S.A. Convention date (U.S.A.) Nov. 3rd, 1936.

The proposed parachute has a canopy and a number of rigid members through which a free passage of air is allowed which are temporarily positioned at spaced points in the interior of the canopy where the latter is packed. These members are of less diameter than the extended canopy and they are withdrawn through the mouth of the canopy when the latter is released for opening.

483,083. *Improvements in or relating to Parachutes.* Pool, J. H., Squadron Leader, Cranwell, Lincolnshire. Dated Oct. 12th, 1936. No. 27,603.

It is proposed to construct a parachute which is automatically prevented from swinging during descent. The parachute is attached to its head by means of lines of differing length so that the canopy is caused to assume a tilted position during descent.

486,343. *Improvements in or relating to Parachute Packs.* Lundholm, C. H., 29, Sveavagen, Stockholm, Sweden. Convention date (Sweden), May 7th, 1936.

The proposed parachute pack has a number of closing flaps at least three of which are held from opening by a common loose locking member and with automatically and manually controlled releasing means for the flaps each having a separate locking pin or pins in which in the closed condition of the pack the loose locking member and all the locking pins are disposed on the same face of the secured flaps and preferably on the outer face thereof.

490,798. *Improvements in or relating to Detachable Pack Parachute Apparatus.* Aerostatica Avorio Societa in Accomandita Semplice, 22, Via Pellegrino, Matteucci, Rome, Italy. Convention dates (Italy), Aug. 17th, 1936, and April 28th, 1937.

The parachute apparatus has a belt, to be worn by the parachutist, having secured thereto a strap having a hook for connection to a pack. The hook is temporarily attached to the belt in a convenient position by a breakable pivot pin which breaks and thus frees the hook when the parachute is used. The belt may comprise inter-connected pairs of metal links. The hook may have a spring-closed detail for securing it to the ring on the pack.

PILOTS AND PILOTING.

484,243. *Improvements in and relating to Apparatus for Training Aviators.* Link, E. A., 10, Avon Road, Binghampton, New York, U.S.A. Convention date (U.S.A.), Sept. 30th, 1936.

The proposed dummy aircraft is rotatably mounted on a support and is controllable by a pupil and is provided with a recording device which marks on a chart the turning movement of the dummy. There may be an autosynchronous motor on the dummy electrically connected with an autosynchronous motor controlling the recording device.

ROTORCRAFT.

487,811. *Improvements in or relating to Aircraft having Rotative Wing Systems.* Societe Anonyme des Ateliers d'Aviation Louis Breguet, 24, Rue George Bizet, Paris, France. Convention date (France), July 20th, 1936.

The proposed aircraft has a pair of co-axial rotating wings revolving in opposite directions and arranged to flap in a plane including the axis of revolution of the wings. Spacing means are provided to prevent the clearance between the wings

falling below a predetermined amount. The spacing means include an abutment lever for each wing, the two levers being interconnected. Each lever is formed at its outer end for operative engagement with the corresponding wing, while its inner end engages an annual member co-axial with the wing revolution axis, the two annular members relating to the pair of revolving wings being interconnected by a linkage.

486,883. *Improvements in and relating to Rotary Wing Aircraft.* Coats, A. G., Gloucester House, Park Lane, London, W.1. Dated Dec. 11th, 1938. No. 34,078.

It is proposed to construct a sustaining blade, so that, with changes in the lift distribution along its span, its general centre of lift moves along a substantially straight spanwise line which passes through the general centre of mass of the blade. As a result there is a predetermined axis of reference in the blade about which there are no fluctuating moments during flight and the blade root attachments or flight control may be so arranged in relation to this axis so as to improve the smoothness of operation of the aircraft.

485,967. *Aircraft with Autorotatable Sustaining Rotors.* The Cierva Autogiro Co., Ltd., Bush House, Aldwych, London, W.C.2. Convention date (U.S.A.), Aug. 8th, 1936.

The rotor blades are independently articulated on an intermediate member about a pivotal axis, the intermediate member being articulated to the hub member on a single pivotal axis, the pivotal axes being so disposed that the motion of the blades about the first axis is principally a flapping motion and that about the second axis is mainly a pitch varying motion, a specified angular movement about the first axis giving rise to a change of pitch angle.

485,299. *Improvements in and relating to Sustaining Rotors for Aircraft.* The Cierva Autogiro Co., Ltd., Bush House, Aldwych, London, W.C.2. Convention date (U.S.A.), Dec. 19th, 1935.

A rotor blade is proposed in which the thickness ratio is decreased from the root to the tip, the chord being uniform throughout. The blade has also a substantially fixed centre of pressure for all normal angles of attack above, say, 2° positive. The blade centre has a rearward C.P. travel below the predetermined minimum. The centre of gravity of the blade coincides substantially or is slightly ahead of the sectional centre of pressure.

484,376. *Rotating Wing Aircraft.* The Cierva Autogiro Co., Ltd., Bush House, Aldwych, London, W.C.2. Convention date (U.S.A.), July 22nd, 1936.

The connections to the hub of the blades of the proposed rotor include screw threaded joints co-axial with the blades, the direction of the threads being such that outward radial movement of a blade is accompanied by an increase of pitch angle, the pitch of the thread being steep enough to ensure that the action is reversible. The blades may be controlled on their threaded joints by fluid pressure which may be operated by the pilot. The blades may be released by a clutch so that they take up the high pitch position under the action of centrifugal force.

485,001. *Improvements in Aircraft Sustaining Rotors.* The Cierva Autogiro Co., Ltd., Bush House, Aldwych, London, W.C.2; Bennett, 22, Grove Way, Esher, Surrey; and Ellis, G. B. L., Uldale, Ewell Road, Thames Ditton, Surrey. Dated Nov. 12th, 1936. No. 30,935.

The proposed self-contained pivotal mechanism for rotor mounting comprises means for transmitting end loads from one to the other of two relatively rotatable pivot parts, which include an elastic member of high resistance to end load and low torsional rigidity and the relatively rotatable parts have in other respects

limited axial freedom relatively to each other. The arrangement is such that the whole end load sustained by the pivotal mechanism is substantially transmitted by the elastic member, which, in contradistinction to the torsionally flexible connections of the above proposals, is relatively short and is wholly contained within the pivotal mechanism.

489,420. *Improvements in or relating to Rotary Wing Aircraft.* Asboth Helicopters, Ltd., 48-49, High Street, Bloomsbury, London, W.C.2, and de Asboth, O., of the same address. Dated Oct. 25th, 1936. No. 9,283.

The rotary wing proposed has two sets of rotary wing blades rotating in opposite directions. The individual blades of each set are rigidly connected to a hub. Each hub is connected to a shaft by a universal joint so as to permit the inclination of the rotor in all directions. The hub has a socket mounted on a spherical member on the shaft and there is interposed between the hub and the shaft means permitting the socket to swivel universally.

490,697. *Improvements in or relating to Rotary Wings or Blades for Rotating Wing Aircraft.* G. and J. Weir, Ltd., Holm Foundry, Cathcart, Glasgow, and Pullin, C. G., 104, Queen's Drive, Queen's Park, Glasgow. Dated Feb. 24th, 1937. No. 5,516.

In the case of blades having tubular spars it is proposed to interpose between the tubular spar and its socket member a rubber sleeve which is vulcanised to these members. The thickness of the sleeve and the degree of vulcanisation of the rubber may be varied so as to provide the resilience desired.

490,741. *Helicopter.* Mitchell, W. M., 320, Aldridge Road, Perry Bar, Birmingham. Dated Feb. 17th, 1937. No. 4,695.

It is proposed that a helicopter should have two or more pairs of rotors, each pair being arranged one above the other and rotating in opposite directions. The rotor blades have adjustable pitch.

SEAPLANES.

483,424. *Improvements in or relating to Seaplane Undercarriages.* The Fairey Aviation Co., Ltd., North Hyde Road, Hayes, Middlesex, and Lobelle, M. J. O., Ludlow, 298, Langley Road, Langley, Bucks.

It is proposed to provide an observation cabin or gun turret underneath the fuselage of a seaplane, the float undercarriage being so arranged that by hydraulic or other means the floats themselves may be moved in flight so as to restrict as little as possible the field of view or of gunfire of the observer or gunner in the cabin or turret.

UNDERCARRIAGES.

488,059. *Improvements relating to Retractable Undercarriages for Aircraft.* Hawker Aircraft, Ltd., Canbury Park Road, Kingston-on-Thames, Surrey, and Chaplin, R. H., The Hearth, Hamm Court, Weybridge, Surrey. Dated July 13th, 1937. No. 19,414.

The proposed retractable undercarriage leg may be a cantilever leg and it is retracted by swinging on a single axis, this axis being inclined to the longitudinal axis of the aircraft and also to the plane in which it is desired to retract the wheel, so that the wheel swings laterally fore and aft and upwardly between its extended and retracted positions.

485,617. *Improvements in or relating to Jacks, more particularly for Retractable Undercarriages for Aircraft.* Onions, J. H., 18, Telford Avenue, Leamington Spa, Warwickshire, and Automotive Products Co., Ltd., Brock House, Langham Street, London, W.1. Dated Nov. 14th, 1936, No. 31,159; and Oct. 11th, 1937, No. 27,577.

The jack described is arranged so that the movement of the plunger relative to the cylinder, produced by fluid pressure, compresses gas contained in a closed chamber within the jack so as to store up energy for moving the plunger in the other direction.

486,955. *Improvements in or relating to Fluid Pressure Operating Jacks.* Automotive Products Co., Ltd., Brock House, Langham Street, London, W.1, and Parker, S. M., of the same address. Dated Nov. 11th, 1936.

This is a fluid operated system of a number of jacks to be operated in unison, each being provided with individual locking means released by the fluid pressure fed to the jack. There is also a valve device which prevents any one of the jacks from being operated until the locking means of all the jacks are released.

483,467. *Improvements in Brake Control Mechanism for Aircraft.* Bendix Aviation Corp., 105, West Adams Street, Chicago, Illinois, U.S.A. Convention date (U.S.A.), Oct. 16th, 1935.

This specification refers to a control mechanism for aircraft wheel brakes which is intended to compensate the variations of volume of the operating liquid in the operating line, such as is due to fluctuations of temperature. The device comprises a pair of wheel brakes for a pair of landing wheels, a pair of wheel cylinders for the brakes, a pair of master cylinders each connected separately with one of said wheel cylinders, means for operating said master cylinders to supply liquid pressure to the wheel cylinders independently or concurrently and to relieve such pressure, and means for maintaining a positive pressure in said wheel cylinders regardless of the subsequent conditions of said master cylinder and of temperature conditions.

486,748. *Improvements relating to Retractable Undercarriages for Aircraft.* Hudson, R. J. H., Yennadon House, Dousland, South Devon. Dated Dec. 8th, 1936. No. 9,607.

The retraction of the undercarriage takes place by rotation about two mutually inclined axes. The connection to the aircraft has an element pivoted about a first axis and carrying a pivot joint substantially perpendicular to the first axes. There is also a part called a constrainer which is connected to the aircraft and to the part by further pivots at an angle to each other and also to the first and second axes.

484,938. *Improvements relating to Breakable Radius Rod or like Elements for Retractable Aircraft Undercarriages.* Aircraft Components, Ltd., and Bound, R. H., both of Arle Court, Cheltenham, Gloucester. Dated Jan. 4th, 1937. No. 237.

A breakable radius rod associated with the operating jack, a connection between the jack and the parts of the rod in the form of a line pivoted to the one part, connected to the jack on one side of the extended alignment of the rod, and extending to the other side of the alignment to a connection to the other part. One of the rod parts supports the jack, the piston is pivoted to one end of the lever which has its fulcrum on that part, the other end of the lever being connected by a pivoted link to the other rod part.

486,936. *Improvements relating to Locking Means for Retractable Undercarriages of Aircraft.* Dowty, G. H., Arle Court, Cheltenham, Gloucestershire. Dated Dec. 9th, 1936, No. 36,014; Jan. 4th, 1937, No. 36,015; Jan. 12th, 1937, No. 36,016.

In an undercarriage operated by a hydraulic jack there is a latch for locking the undercarriage down, which latch is connected to the jack through other connecting means affording positive connections in one sense and non-positive connections in the opposite sense. During lost motion between the jack and the undercarriage the jack operates positively to unlock the latch before retraction, the same thing also taking place before extension.

486,461. *Improvements in Retractile Undercarriages for Aircraft.* Willoughby, P. N., and the Willoughby Delta Co., Ltd., both of Bank Buildings, 20, Kingsway, London, W.C.2. Dated Feb. 4th, 1937. No. 3,350.

The proposed device consists of a rigid main strut hinged at its upper end to the wing, the shock absorber being mounted at its lower end. There is a two-part drag strut hinged to the wing and to the main strut, and a two-part radius rod hinged to the wing and to the main strut. When extended, the elements form a rigid tripod Vee arrangement being folded sideways towards the wing.

485,414. *Improvements in or relating to Self-Folding Struts for Aeroplane Landing Chassis.* Societe d'Inventions Aeronautiques et Mecaniques S.I.A.M., 1, Route des Alpes, Fribourg, Switzerland. Convention date (France), May 26th, 1936.

The proposed retractable gear has a self-folding strut composed of two spaced elements joined together by means of a third element articulated to the spaced elements. The elements of the strut are articulated at their outer ends, one to a carrier leg and the other to a pin mounted on the aeroplane. The members can be extended or folded by an extensible driving member, the driving member being articulated by one of its ends to one of the three elements, and by its other end to one of the other two elements.

490,087. *Improvements in Retractable Undercarriages for Aeroplanes.* Mercier, J., 131, Boulevard de la Seine, Neuilly-sur-Seine, Seine, France. Dated May 13th, 1937. No. 13,524.

The proposed undercarriage is intended for aircraft having high or mid-wings. Each wheel is suspended from the lower end of a member having the form of an elbow and shaped so as to mate with the fuselage and wing in the retracted position. The upper end of this member is hinged to the fuselage and to its upper part is attached a strut arrangement which operates the undercarriage for retracting or extending. This strut may be actuated by pneumatic, hydraulic, or other means.

489,385. *Improvements in Retractable Undercarriages for Aircraft.* Willoughby, P. N., and the Willoughby Delta Co., Ltd., Bank Buildings, 20, Kingsway, London, W.C.2. Dated Feb. 4th, 1937. No. 3,351.

This retractable undercarriage is intended for use with high wing monoplanes and is arranged for mechanical operation. There are two similar arrangements of hinged struts in parallel connected so as to be laterally rigid. Each arrangement consists of three struts forming a three-bar linkage hinged at its outer and upper ends to fixed members. There is a stabilising strut, one end of which slides along one of the three struts to produce rigidity, a radius rod and a shock absorbing strut.

486,211. *Improvements relating to Retractable Undercarriages for Aircraft.* Aircraft Components. Ltd., and Bound, R. H., both of Arle Court, Cheltenham, Gloucestershire. Dated Dec. 31st, 1936. No. 35,859.

The retraction jack is pivoted to one part of a breakable rod the jack being also pivotally supported about the same axis as that of the leg pivot. The connection between the jack and the rod part lies between the pivotal connections of the rod to the aircraft and to the leg. There may be locking means actuated by lost motion.

489,391. *Improved Form of Retracting Undercarriage for Aircraft.* Boulton, Paul Aircraft, Ltd., The Airport, Wolverhampton, and Hughes, H. A., Westfield, Keeper's Lane, The Werqs, near Wolverhampton. Dated Feb. 25th. No. 5,633.

The proposed undercarriage has two legs carrying wheels hinged at their upper ends to a common supporting member. This moves vertically within the aircraft for the purpose of raising the legs. Each leg carries a part engaging with guide slots fixed within the body so that as the legs are raised they are also caused to rotate into a more nearly vertical position, so that legs which protrude laterally may be withdrawn into the body.

CORRESPONDENCE.

To the Editor of the JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY.

SIR,—From the viewpoint of the pilot I was particularly interested in Mr. Weyl's letter in the August Journal, dealing with lateral stability with special reference to his Dart Kitten.

Appearing as it does in so august a journal I feel compelled to challenge some of the statements and claims it makes, especially as I have recently done a considerable amount of flying near and beyond the stall on one of these machines.

Although I found it possible to fly the machine stalled, it was rather a tricky and uncertain business, and I do not think that by any reasonable stretch of imagination it could be scientifically said to possess " complete aileron control " when stalled. Likewise, although it was possible sometimes to keep it " sinking on an even keel " it more usually insisted on dropping a wing in the all-too-common incipient spin manner. I agree that the tail buffeting was mild.

Nevertheless, considered as a conventional aeroplane, I think that the Kitten is a pleasantly docile machine in view of the amount of wing taper used, and I have enjoyed flying it; but to claim that it is fool-proof at the stall would, I think, be misleading and unwise.—I am, Sir, yours faithfully,

W. E. GRAY.

15th September, 1938.

REVIEWS.

TEACH YOURSELF TO FLY. Nigel Tangye, R.A.F.O. English Universities Press, London. 2/- net.

This is the latest of a series of very excellent " Teach Yourself " manuals published by the English Universities Press at a remarkably low price. Mr. Nigel Tangye brings many qualifications to the preparation of this book. He is a well-known writer on aeronautical matters, holds a " B " licence and the Air Ministry Instructor's Certificate and has given many demonstrations at flying meetings, including the late R.A.F. display at Hendon.

As one would expect, Mr. Tangye has written a thoroughly sound book on how to fly. Chapter I explains in simple accurate language the use of the controls and the essential instruments. The author does not, as many books on flying do, leave the question of taking-off and landing till the novice has learnt to fly. He takes things in their proper order and explains what the budding pilot must do in order to become a proficient one. So Chapter II deals with taxying. The chapter is full of good hints, of which the last is not by any means the least, " Never move an inch without making quite certain that there is not a lawn mower or something else in your way."

Chapter III is concerned with taking-off, Chapter IV with flying straight and level, and Chapter V with stalling, climbing and gliding. They are followed by chapters on turning, approaching and landing, spinning, cross-country flying, and aerobatics; an excellent chapter.

Mr. Nigel Tangye is to be congratulated on the production of a first class book on the subject, which cannot but be of real help to the many new enthusiasts now learning to fly through the Civil Air Guard and other sources.

G. OTTO: " LEITWERK," VOL. III OF " ENTWURF UND BERECHNUNG VON FLUGZEUGEN " (Tail Group, Vol. III of " Design and Calculation of Aeroplanes)." Publ. by Verlag von C. J. E. Volckmann Nachf. E. Wette. Berlin-Charlottenburg 1938. 87 pp., 87 figs. and 9 graph. tabl. Price RM. 3.50.

The present volume of this work (Vols. I and II have previously been reviewed in this JOURNAL) deals with the loads acting on tailplane, elevator, fin and rudder in accordance with the German load requirements of 1936. As an example, a complete stress calculation of the Heinkel He.72 type " Cadet " tail group is given. The application of the load requirements is fully explained and the loads calculated by means of prescribed empirical functions for the pressure distribution. A third chapter gives examples of the actual stressing and dimensioning of a conventional tail group structure. A later chapter refers to the choice of shapes and to constructional details, to elevator and rudder balances (the Flettner auxiliary rudder being considered the most common one), to trimming tabs, etc. The author mentions that cut-outs in the elevator (for the rudder) of 15 per cent. of the original elevator area resulted in a loss of 20 per cent. of the static stability.

Like the preceding volumes the present one is well and clearly written and may be recommended as a good example of stressing practice. But it is neither a reference book nor will it replace a class book for the student.

CL. BOEHNE: "WERKSTOFFKUNDE FUER DEN FLUGZEUG- UND MOTORENBAU" (Materials for Aeroplane and Engine Construction). Vol. 28 of "Flugzeugbau und Luftfahrt." Publ. by C. J. E. Volckmann Nachf. E. Wette. Berlin 1937. 129 pp. with 86 figs. Price RM. 3.40.

The author is an instructor at a technical school of the German Air Force, and his book is intended to be an instructional manual for students, pilots and mechanics. It is well and comprehensively written and deals with the matter from a purely practical view point.

The problem of "Ersatz" materials is well considered and modern aeronautical materials (like plastics, compressed wood, resin glues, etc.) are described with many and valuable data. With regard to stainless steels it is stated that they are exclusively used with seaplanes and even then to a small extent only (control parts near magnetic compasses), and that the spot welding of cold rolled stainless steels is still in the experimental stage in Germany, due to the shortage of chromium and nickel. The ageing problems of cold worked steels are considered important for aircraft parts. The weldable "Izett" steels are mentioned as being safe against brittleness due to age and, therefore, essential for fittings, and safer with regard to welding cracks. A statement that gear wheels made of plastics cannot run hot seems to be open to doubt. Dopes, paints and varnishes are treated shortly but well. Modern methods of protective coating are described.

The book should be of value to everybody desiring a sound introduction into the problems of aeronautical materials.

"JAHRBUCH 1937/38 DER DEUTSCHEN AKADEMIE DER LUFTFAHRTFORSCHUNG" (Yearbook 1937/38 of the German Academy of Aeronautical Research). Publ. by Verlag R. Oldenbourg, Munich. 321 pp. with phot. portraits and 20 figs. Price RM. 10.—.

It would seem that the "German Academy for Aeronautical Research" (founded in 1936 by the German Air Minister) cannot be considered a scientific society in the current sense but a sort of Government Advisory Body (not unlike the Aeronautical Research Committee of this country). It is a board of engineers and scientists selected by the German government. Its members are expected to produce certain technical or scientific work under a working discipline, and it is guided by principles conforming to the ideas of the present German régime. According to the laws of this Academy the selection of scientific engineering leaders and the co-ordination of the different branches of general science with aeronautics are aims to be achieved. The president is the German Air Minister, and he chooses the members and officers. Up to 60 ordinary members and up to 100 corresponding members form the community of the Academy. Foreigners may be elected corresponding members and among those from England are Prof. L. Bairstow, Prof. B. Melvill Jones, Dr. D. R. Pye, Prof. R. V. Southwell, G. I. Taylor, Sir H. Tizard. There are eight Italian scientists, six American and one from Sweden. The ordinary members are nominated for five years, thus forming a kind of a scientific parliament in which each member is compelled to produce at least one lecture of aeronautical importance during scientific sessions within his term.

Statutes and regulations of the Academy provide explanation for the fact that a number of eminent scientists hitherto considered as typical representatives of the *German* aeronautical science cannot be traced among its members; well-known names such as v. Kármán, v. Mises, H. Reissner, H. G. Kuessner, L. Hopf, R. Fuchs, O. Schrenk, Trefftz, A. Lippisch, to mention only a few, are not among the list of the elected and chosen people, thus giving proof that this Academy is scarcely to be considered an Academy in the sense of a "Royal Society" in this country or the French Academy which formed the origin of bodies of a purely scientific nature.

The present first volume of the German Academy gives a list of all members, their achievements and qualifications (often with a portrait) and a useful list of publications of the ordinary members. An appendix contains a presidential speech and a paper read by E. Houdremont dealing with material and technical problems of the steel industry.

BARON E. VON LOEWENSTEIN: " DER FRONTFLIEGER " (The Front Line Airman). Diary Notes. Vol. 81 of " Deutsche Tat im Weltkrieg 1914/18." Berlin 1937. Publ. by Verlag Bernard & Graefe. 274 pp. with figs., photographs, tables and maps in a separate cover. Price RM. 6.25.

This book is neither a novel nor a story but an unrevised collection of diaries kept by the author who, being an officer on the active list, served during the war with the German Army Air Corps.

He joined one of the Army Flying Battalions several months before the war, was trained as an air observer, served as such in Russia and France and finished his war career as a commanding officer of Artillery Observation, Army Long Reconnaissance and Independent Bombing Squadrons in France.

As in the military war literature, recollections of air observers are scarce, and for this fact alone, the book would deserve interest. It is obviously written by a trained army officer who is conversant with the ideas of tactics and strategy taught at the Prussian War Academy based on the work of Clausewitz and Moltke, and by a soldier who is accustomed to strict discipline. His diary gives more than facts and impressions; more valuable, to-day, perhaps, because obsolete experience and criticism are also incorporated, criticism which often does not refrain from sharp self-criticism.

In a technical sense the author (who had no training as a pilot) has not much to say. Flying in Poland and Russia, at the beginning of the war, he carried out strategical reconnaissance on Jeannin " Stahltaube " monoplanes, clumsy slow air vehicles with a maximum speed of about 60 m.p.h. and a service ceiling of 2,000-3,000ft. (reached after a climb of 45 min.). The author had been told that bullets would not go higher than approximately 2,500ft. They carried small bombs and steel darts against the Russians with the Jeannin pigeon. The reconnaissance work was done by eye, and misleading reports did a certain amount of harm aggravated by the lack of organised aerial survey and correct maps.

Early in 1915, the military organisation (with which originally were grouped the Air Squadrons among the Army Transport Services) improved, the first air cameras were issued and biplanes with a superior performance, and, as a consequence of successful attacks by Russian fighters, armed observation aeroplanes were being introduced. From 1916, the author was sent to France, doing army observation work and occasionally encountering Guynemer. His squadron suffered severe losses (23 machines during a month with a nominal strength of 4-6 machines), and the author honestly described his anxieties during ground attacks he made. In the summer of 1918, he became C.O. of an Army Reconnaissance Squadron. Long distance flights of 5-7 hours endurance were carried out at heights up to 20,000ft. and more. Official orders, reports and service instructions are often quoted.

Of interest is the experience of the author that flying personnel recruited from front cadres of the infantry often proved unsuitable for the strain of war flying, during which they had to fight alone. The author, therefore, preferred young pilots without any previous service at the front. Valuable notes concern camouflage (well illustrated by pictures).

As the author is no writer his book is not too enjoyable to read. But it is truthful and contains real experience seen with the eye of a professional soldier.

TWENTY-SIXTH WILBUR WRIGHT MEMORIAL LECTURE.

The Twenty-Sixth Wilbur Wright Memorial Lecture was given at the Institution of Mechanical Engineers, Storey's Gate (by permission of the Council of the Institution), on Thursday, May 26th, 1938, by Dr. H. J. Gough, M.B.E., D.Sc., M.I.Mech.E., F.R.S., on " Materials of Aircraft Construction," before a distinguished audience.

In the chair, Mr. F. Handley Page, C.B.E., F.R.Ae.S., Vice-President of the Society.

The CHAIRMAN: This was the most important lecture read before the Royal Aeronautical Society during the year. It was given in honour of Wilbur Wright, who, with his brother Orville Wright, were the first men in the world to fly a power-driven heavier-than-air craft under control.

The lecture was delivered alternately by a lecturer from abroad and one from this country. This year we were more than fortunate in getting Dr. Gough to lecture on the subject of " Materials of Aircraft Construction."

On the occasion of these lectures, it has been the custom of the Society to send a telegram to Mr. Orville Wright, and one was sent in the following terms:—

> " Council and Guests of Royal Aeronautical Society send you heartiest greetings on the occasion of the reading of the twenty-sixth Wilbur Wright Memorial Lecture by Dr. Gough on Aircraft Materials which reveals the astounding progress made in the short space of thirty-five years since you and your distinguished brother, whose name we honour to-night, made your first flights in a power-driven controlled heavier-than-air craft.
>
> HANDLEY PAGE, *Vice-President.*"

The following reply was received:—

> " Dear Mr. Handley Page,—Please extend to the Council and Members of the Royal Aeronautical Society my sincere thanks for the heartiest greetings on the occasion of the reading of the twenty-sixth Wilbur Wright Lecture by Dr. Gough.—Sincerely yours,
>
> ORVILLE WRIGHT."

He owed Dr. Gough an apology, continued the Vice-President, in that he must recite his distinguished career to an audience who knew him as one of the most brilliant engineers in this country.

Educated at London University and apprenticed to Messrs. Vickers, Ltd., Dr. Gough joined the scientific staff of the National Physical Laboratory in 1914. In that year and for the next three years he served with the Royal Engineers in France and Belgium, was mentioned twice in despatches and given his commission in the field. In 1930 he was appointed Superintendent of the Engineering Department of the National Physical Laboratory and has published over 50 papers on engineering subjects and given many lectures.

Among the many letters he is able to put after his name are F.R.S., D.Sc., Ph.D., M.I.Mech.E., but he has yet to place the most important letters of all, F.R.Ae.S.

MATERIALS OF AIRCRAFT CONSTRUCTION.

By H. J. Gough, M.B.E., D.Sc., M.I.Mech.E., F.R.S.

CONTENTS.

Introductory.

Part I: The Wright Engine and Plane.

Part II: Some Typical Features of Aircraft of 1938.

Part III: Technical Survey of the Aircraft Materials.

A. Metals and Alloys.

1. Steels.
2. Alloys of the Light Metals.

(*a*) *Aluminium Alloys.*

(1) *Wrought Aluminium Alloys.*
Heat-Treatable Alloys containing Copper and Magnesium.
Heat-Treatable Alloys not containing Copper.
Non-Heat-Treatable Alloys.

(2) *Cast Aluminium Alloys.*
Copper and Copper-Zinc Alloys.
Silicon Alloys.
Heat-Treatable Cast Alloys.

(*b*) *Magnesium Alloys.*
Casting Alloys.
Wrought Alloys.

3. Some Special Alloys.

B. Wood.

C. Rubber.

1. Natural Rubber.
2. Synthetic Rubbers.
3. Bonded Rubber and Metal.
4. Expanded Rubber.

D. Plastics.

E. Methods of Surface Protection.

Part IV: Essential Parts of Aircraft in Relation to Their Materials of Construction.

A. The Engine.

1. Pistons.
2. Bearings.
3. Valves.
4. Crankshafts.
5. Connecting Rods.
6. Gears.
7. Crankcases.
8. Cylinder heads.
9. Superchargers.
10. Flexible Transmission Couplings and Engine Mountings.

B. The Air-Frame.
1. The Development of the All-Metal Aircraft in Light Alloy.
2. Construction in Wood.
3. Construction in Plastic Materials.

C. The Airscrew.
1. Wooden Propellers.
2. Aluminium Alloy Propellers.
3. Steel Propellers.
4. Magnesium Alloy Propellers.
5. Airscrews containing Laminated, Impregnated and Compressed Woods.
6. Airscrews of Reinforced Synthetic Resin.

D. The Landing Gear.
1. The Undercarriage.
2. The Wheel and Tyre.

Part V: Notes on Some Characteristics of Metals.
1. The Primary Problem.
2. Fatigue.
3. Fretting Corrosion.
4. Abrasion and Wear.
5. Damping Capacity.

Acknowledgments.

LIST OF ILLUSTRATIONS.

FIG. NO. TITLE.

1 The First Controlled and Sustained Flight, December 17, 1903.
2 The de Havilland " Albatross."
3 The de Havilland " Albatross." A. Fuselage in Construction; B. Central Box of Wing.
4 The " Short-Mayo " Composite Aircraft.
5 The " Empire " Flying Boat; Sketches showing Features of the Construction of the Hull and Wing.
6 The " Empire " Flying Boat; Main Spar of Wing and Hull Section.
7 The Fairey " Battle."
8 Constructional Details of the Fairey " Battle."
A. Stressed Skin Fuselage.
B. Wing Spar Box.
9 A. Bristol " Hercules HE—IM " (Sleeve Valve).
B. Bristol " Pegasus XX " (Poppet Valve).
10 A. Rolls-Royce " Merlin II."
B. Napier-Halford " Dagger III."
11 1 and 2. Nitrided Steel Crankshafts.
3. Sodium-cooled Exhaust Valve and Insert; nitrided stem, stellited seating, head covered with 80-20 Ni. Cr. Alloy.
4. Reduction Gear Assembly in Cast Aluminium Alloy Casing.
5. Connecting Rod and Bearing Assembly.
6. Forged Aluminium Alloy Piston, Steel Gudgeon Pin, etc.
12 1. Supercharger Impellor. A. Aluminium Alloy; B. Steel.
2. Supercharger Assembly; Casing of Cast Aluminium Alloy.
3. Cast Aluminium Alloy Cylinder Block (with camshaft drive and valve mechanism in position, and liner detached).
4. Forged Aluminium Alloy Cylinder Head.
5. Forged Aluminium Alloy Crankcase.

FIG. NO. TITLE

13 Windscreen and Navigation Window of Transparent Synthetic Resin.
14 The " Santos-Dumont " Aeroplane of 1906.
15 A Landing Wheel of 1938.
16 Extruded Sections of Aluminium Alloys. Typical Examples and Applications.
17 " Heavy Alloy " containing 90 per cent. W., 4 per cent. Cu., and 6 per cent. Ni.
A. Microstructure.
B. Welded Test Piece.
C. Group of Balance Weights.
18 Tests on Laminated, Compressed and Impregnated Wood (six of birch, one of beech, also solid birch).
19 Stage in the manufacture of one type of Airscrew block made of laminated and compressed wood.
20 *Tests on Rubber Bonded to Metal.*
A. Specimen unstressed.
B. Specimen under load.
C. Fractured specimen.
D. Shear-deflection curves on samples having different hardness values.
21 *Failures.*
A. Crankpin Failure commencing at Grinding Cracks.
B. Crankshaft Failure commencing at Oil Hole.
C. Piston Failure by Flexing Action.
D. Gudgeon Pin Bending Failure, commencing at inner surface due to local defect.
22 Diagram illustrating Softening and Technique for Deduction of Heat Flow in Pistons under Running Conditions by Method of Hardness Survey.
23 *Bearings.*
A. Increase of Load and Speed in Big-End Bearing.
B. Lead Bronze Bearings; microphotograph showing lead segregation.
C. Radiographs of Lead Bronze Bearings. (i) Porosity and lead segregation; (ii) a satisfactory bearing.
24 *Failures.*
A. Various Types of Failure in Connecting Rod Assembly.
B. Eye of Master Rod; failure started by " fretting."
C. Diagram illustrating increase of gear-tooth loading; period 1928-1938.
D. " Scruffed-up " Reduction Gear Pinion.
25 *Failures.*
A. Aluminium Alloy Crankcase; failure due to internal stresses.
B. Steel Airscrew Shaft; failure commenced at fretting on splines.
C. Steel Camshaft; failure due to torsional vibrations.
D. Steel " Spring Drive " Shaft; failure due to shock loading and stress concentrations.
26 *Engine Mountings Employing Bonded Rubber.*
A. A Mounting and its Application to a Radial Engine.
B. A Mounting for In-line Engine; rubber partly in compression, partly in shear.
C. Another type for In-line Engine; rubber in shear.
27 The " Silver Streak " of 1919; all-metal construction of light alloy.
A. Fuselage Construction.
B. Engine Mounting.
28 A. Early Spar of Spruce.
B. A form of Thin Sheet Steel Spar.
C. Simple Spar of Rolled Light Alloy.
D. Typical Wing Section of Monoplane.

FIG. NO. TITLE

E. Stringer of very efficient form.
F. Common but poor type of Stringer.
G. Asymmetrical design of Stringer.
H. Tubular Stringer (R.A.E.).
J. Stainless Steel Forging for Attaching Wing to Hull of Flying Boat.
K. Typical closed Stringer Sections for Land Plane.
L. Front or Rear Spar Section of Wing.
M. Typical Duralumin Spar Section for Biplane.

29 The Bristol " Blenheim."
A and B. Fuselage.
C. Wing; centre and outer sections on assembly jigs.
D. Nose end of Body.

30 Method of Mounting Engine on Wooden Wing Construction.

31 Beam Tests on Wooden Box Spars.

32 Some Applications of Compressed Wood locally reinforced against Shear.

33 Sketches showing details of proposed Aircraft of Moulded Plastic Construction.

34 Grain Flow in the Blade Root Flange of a Duralumin Variable Pitch Airscrew.

35 A. Magnesium Airscrew; 1,010 h.p., weight of each blade 58½lb., total weight 344lb.
B. Showing transition from block to blade in compressed wood construction.
C. Dissembly of Magnesium Blade, showing special " anti-fretting " bush.
D. Dissembly of Hub of Compressed Wood Screw, showing special sleeve.

36 A. Internally Sprung Landing Wheel; High Tensile Steel Forged T-piece sliding in Magnesium Alloy Castings.
B. Casings of Engine-Driven Rotary Pump for Hydraulic Actuating Gear; of low expansion Silicon-Aluminium Alloy Castings.

37 A. Frequency Curve of Fibre Length of Raw Cotton used in Aeroplane Tyre Cord.
B. Tensile Load Elongation Diagram to Fracture of typical Aeroplane Tyre Cord.

LIST OF TABLES.

TABLE NO. TITLE.

1 The 1903 Wright Engine; Probable Materials of Construction.

2 A General Analysis of the Materials of Construction of Three Modern Aero Engines.

3 Approximate Sequence of Changes, during the past thirty years, in the Materials Used for Four Important Engine Components.

4 Physical Properties of " Heavy Alloy ": 90 per cent. W., 4 per cent. Cu., 6 per cent. Ni.

5 Description of Samples of Natural and Laminated Wood.

6 Mechanical Properties of Some Reinforced Synthetic Resins.

7 Relative Characteristics of Structural Materials.

8 General Comparison of Reinforced Timber and a High Strength Aluminium Alloy.

9 Specific Properties of an Aluminium Alloy, a Reinforced Timber and a Plastic Material.

10 Three-Bladed Airscrews designed to absorb 1,600 h.p. at 2,750 Engine r.p.m.; Design Speed 250 m.p.h. at 10,000 feet.

11 Size Effect: Experiments Made Using Polished Specimens Free From Sudden Changes of Form.

INTRODUCTORY.

The Wilbur Wright Lectures not only commemorate that pioneer flight on which the art of practical aviation was founded but also offer homage to the brilliant research and invention which made that flight possible. It is, therefore, natural and fitting that such a large proportion of the preceding 25 lectures have dealt specifically with the application of research to matters aeronautical. The materials of aeronautical construction can also justly be classed as the outcome of much research into many fields of pure and applied science, with practical results that have made some contribution towards the advancement of aviation and, hence, fittingly form the subject of a Wilbur Wright Lecture. Accordingly, when the Council of the Royal Aeronautical Society honoured me with the invitation to deliver the 1938 lecture on this subject, I naturally read up the preceding lectures and was somewhat surprised to find that materials, as such, had not previously been dealt with in this connection. The task of making the first survey of a field of such alarming scope, in a necessarily limited space and time, involved some anxious reflection regarding a suitable method of treatment; it appeared that a detailed discussion of personal research, or even of a selected group of materials, must have such a limited scope as to be incompatible with what is implied in the allotted title. To the casual observer, the really wide range of the more familiar materials of construction that have been available for some years, allied to the normal steady improvements that have been effected and those that may be expected, may appear to offer all that is required for the aeronautical requirements of the next decade or so, so that reviews of the materials of, say, 1924, 1931, 1938 and 1945 would mainly represent a story of *development* rather than *change*; actually, this is *not* the position. A relatively few years has seen the relinquishment, temporary or permanent, of the position held by steel as a structural material; the use of light alloys has become very general, an improved form of wood is definitely in the field while it may be that the entire structure of moulded plastics will become a practical proposition in the fairly near future. Then, the accomplishment of the aims of the engine builder with regard to units of much greater powers are retarded to a certain extent by the fact that a number of materials appear to have reached the visible peak of their development; new materials are urgently required. Again, who would care to prophesy that the airscrew of the future 2,000-4,000 h.p. engine will even be made of any kind of metal, although the present aluminium alloy propellers give such good performance.

Reflections of this kind indicated that probably never has the general position of aircraft materials passed through such an interesting period of rapid development and change as at the present time and, hence, it appeared worth while and appropriate to attempt the task of placing on record a descriptive account of the present position, indicating the materials used, the extent by which they meet or fail to satisfy existing requirements, together with a mention of some promising developments which are being pursued. I am now fully aware that the plan was too ambitious and foredoomed to failure, one reason being the lack of sufficient time given to me for the task. But I desire to ascribe whatever degree of partial success may have been attained to the most generous response received, from many friends within and outside the aircraft industry, to my requests for information and advice; everybody approached has gone to much personal trouble to assist in every way possible, and has afforded greatly valued collaboration.

The general scheme of the lecture may be briefly summarised thus:—To throw up in relief the developments that have taken place in the period 1903-1938, the brief description of the materials of the Wright engine and plane—given in Part I—is followed in Part II, by a short discussion of some typical features of representative British aircraft of 1938. Part III attempts a summarised technical survey of the principal aircraft materials available—steels, light alloys, special alloys, wood, plastics and rubber—together with a note on the very important aspect of the methods of surface protection. In Part IV, discussion turns to the

essential parts of aircraft in relation to the materials employed and the imposed operating conditions, revealing directions in which research attention can usefully be directed; for convenience, the aspects of the engine, airframe, airscrew and undercarriage, are separately considered, mention being made of some interesting current experimental developments. Part V consists of some notes on some especially interesting characteristics of metals and it may be remarked that time has not permitted the more detailed consideration to these aspects that was contemplated when the lecture was planned. At the conclusion of this most interesting task and after reading over what has been written, I am conscious that the recorded position is obviously that as seen by an engineer; the subject lends itself to a variety of treatments and, in other hands, an entirely different balance might result. For all such errors of commission and omission, I tender my regrets.

I would conclude these remarks by expressing to the Council of the Royal Aeronautical Society my deep appreciation of the honour conferred in their invitation to undertake the preparation and delivery of the 1938 Wilbur Wright Lecture.

Part I.

The Wright Engine and Plane.

It is impossible, with the present available space, even to sketch in broad outline the *process* of development of the materials of aircraft construction during the period 1903 to 1938, but an impression of the changes that have taken place may, however, be gained by a comparison of some of the principal materials used in the outstanding features of construction of some typical aircraft of to-day, considered in relation to those of the famous plane invented by the Wright brothers.

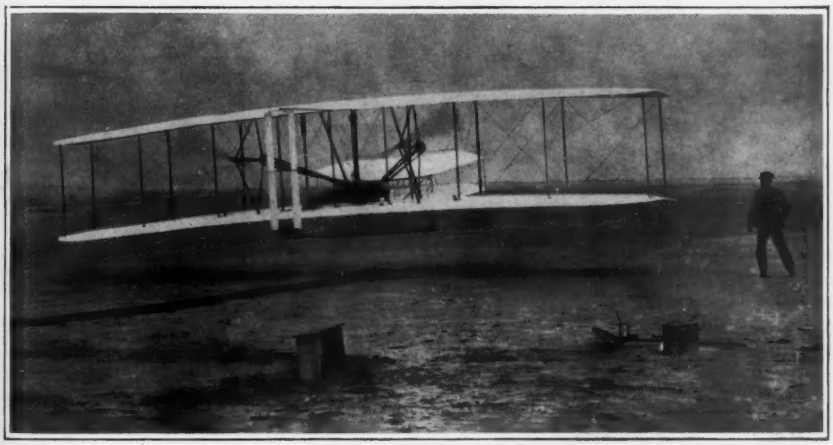


Fig. 1.

The first controlled and sustained flight, December 17, 1903. Orville Wright piloting the machine; Wilbur Wright on foot.

Fig. 1 shows that epoch-making event, man's first flight made under controlled and sustained conditions in a power driven aeroplane, on the 17th December, 1903. Four flights were made on that day, the longest of which lasted 59 seconds and covered a distance of 852 feet over the ground against a 20 m.p.h. wind. Orville Wright made the first flight and is seen piloting the machine, while Wilbur,

in whose honoured memory this lecture was founded—and who is seen on the right of the photograph—piloted the machine on its fourth flight of 59 seconds. What were the principal materials of construction of this craft? To answer this question a careful search has been made of the literature for an accurate record but with most disappointing results, while a number of personal enquiries, made in this country regarding probable materials, have yielded but little further information. Mr. Griffith Brewer has been good enough to take considerable interest in this matter and has obtained from Mr. Orville Wright his recollections regarding the materials used. As a result, it is now certain that the piston and cylinders were of fine-grained grey iron of a high quality as used at that time for high pressure steam valves, etc.—tests made by the Wrights showed this iron to have a tensile strength of 39,000lb./in.^{2}; also, the crankshaft was of high carbon (tool) steel, not heat-treated after being cut from a slab. Some information of a more general nature regarding a few other components has also been revealed by Mr. Wright; the cylinder liner and piston were of cast iron; the crankcase and cylinder block were of an aluminium alloy; the connecting rod was of seamless steel tubing screwed into phosphor bronze big-ends; the bearings—crankshaft, propeller shaft and camshaft—were of babbitt metal; the valves had steel stems and cast iron heads; the chains driving the propellers were No. 155 diamond roller chains.

TABLE I.

THE 1903 WRIGHT ENGINE: PROBABLE MATERIALS OF CONSTRUCTION.

Component.	Probable Material and Approximate Composition.	Approximate Tensile Strength of Materials of that Period. (tons/in^2)
Crankshaft	Forged Tool Steel (0.9/1.0% C.)	55/65
Connecting Rods	Seamless Steel Tubing (0.4% C.)	40
Camshaft	Steel (0.15/0.25% C.)	28
Timing Gears, Chain Sprockets	Carbon Steel (0.4% C.)	40
Chain Driving Propellers	Case-hardened Steel (0.4% C.)	45
Valve Stems	Carbon Steel (0.4% C.)	40
Valve Springs	Carbon Steel (0.5/0.7% C.)	70/80
Oil Sump, Induction Chamber, Radiator, Ignition Chamber Cover, Petrol Tank	Sheet Steel, tinned (0.25% C., 0.6% Mn.)	26
Cylinder Liners, Pistons, Valve Heads, Flywheel	Grey Cast Iron: fine-grained	17½
Cylinder Block, Crankcase	Aluminium Alloy (92% Al., 8% Cu.)	10
Big Ends	Phosphor Bronze (90% Cu., 10% Sn., 0.25% P.) without liners	18
Bearings	Babbitt (88% Sn., 4% Cu., 8% Sb.)	

The engine was constructed by the Wrights; it developed approximately 12 h.p., weighed about 180lb. and consisted of 4 cylinders in line, water-cooled, of 4in. bore and stroke. The constructors developed no new materials for this engine, and the materials used represented general engineering practice of that period. The information supplied by Mr. Orville Wright, together with the results of a careful search of the relevant technical literature and other publications of the time has enabled an estimate to be formed of the principal materials which were probably used in the 1903 engine and this estimate is given in Table I and is, of course, subject to correction.[1] The aluminium alloy, phosphor bronze and babbitt were secured from John Hoban and the compositions stated

[1] Note.—As a matter of historical interest, this engine should be dissembled and an exact determination made of the materials used. Using micro-chemical methods, the damage caused would be negligible.

have been supplied by the Hoban Brass Foundry as relating to the alloys used by them at that time; the remaining materials were those employed in general engineering practice, and the detailed data are quoted from various writings of the period.

Turning to the structure of the Wright machine, much less doubt exists concerning the materials used. They were wood, cloth, and wire for bracing purposes. The woods were silver spruce, grown in the eastern states of the U.S.A., also, second growth ash; the tensile and compressive strengths of the spruce, in the direction of the grain, can be reasonably assessed at about 8 and 2¼ tons/inch^2, respectively. The two propellers—which gave a thrust efficiency of 66 per cent.—were also spruce; they were of the " built-up " type of construction. The fabric was "Pride of the West " muslin as sold over the counter in 1903; it was not doped. A specially interesting point about the use of this cloth—which, in fact, constituted one of the claims of the Wright patent[3]—was that it was cut on the bias, having the threads situated diagonally to the lateral spars and the longitudinal ribs with which it formed truss systems. By this combination and arrangement " we secure a surface of very great strength to withstand lateral and longitudinal strains, but capable of some twisting movement." No record can be traced of the strength of this cloth and surmise is not profitable. The bracing wires, of circular cross-section, consisted of ordinary piano wire and, as such, would be of plain carbon steel probably having 0.6 per cent.-0.8 per cent. C. content and a tensile strength of something between 80 and 120 tons/sq. inch.

Such were the materials carefully selected by the Wrights for the best possible combination of lightness and mechanical strength. The total wing area was about 510 sq. ft. and supported about 750lbs. in the flights made on December 17th, 1903, a wing loading of a little less than 1½lb. per sq. ft.; the speed of the plane in still air was estimated at 31 m.p.h. In producing this famous biplane, and achieving their historic flight, they started a quest for ever lighter and stronger materials with such far-reaching results that have made possible not only the aircraft of to-day and to-morrow, but have also proved of inestimable value to every other branch of engineering construction and technical development. The impetus given to the science and art of the materials of construction probably owes more to the successful flight so modestly, but confidently, made in December, 1903, than to any other single influence; the names of Wilbur and Orville Wright will always be honoured in much wider circles than those of aeronautical engineering.

Having thus taken a brief glance at the biplane and materials of aircraft construction of 1903, and passing over the intervening period of great development, we may turn to some features of typical aircraft of 1938 with respect to the materials of which they are built.

Part II.

Some Typical Features of Aircraft of 1938.

Having previously glanced at the materials of the Wright plane, the object of the present section is to review, in an equally broad manner, the present principal aircraft materials and their chief uses. The most convenient way to do this, in the first place, is by a brief discussion of representative modern engines and aeroplanes. With regard to the power unit, no especial difficulty arises. The constant urge for ever-increasing power, so largely accelerated by the use of improved fuels and supercharging, has, as far as the materials of construction are concerned, introduced two primary problems which may be classed as thermal and mechanical. Only those materials best suited to meet these searching demands can find a place in high duty engines and while wide opportunities exist for the most skilful design and production yet, to quite a considerable extent,

[3] British Patent No. 6732. A.D. 1904. " Improvements in Aeronautical Machines." Orville and Wilbur Wright.

the use of the various available materials is clearly determined. The structural position is, however, quite different. It appears to be accepted that, given the same high degree of designing skill, a modern aeroplane could be produced equally efficiently, from aerodynamic and weight points of view, if constructed essentially of wood, steel, or light alloy, and excellent examples of each construction are in flight to-day. And yet the impression of the construction of 1938 is mainly that of light alloy. The all-steel aeroplane, brought to such a high state of perfection in the years immediately following the war has temporarily, at any rate, rather faded into the background. For reasons the replacement of the biplane by the monoplane with much deeper wings and subjected to increased loadings is partly responsible, while the really remarkable development of extruded light alloy sections of simple shapes and tapering dimensions is undoubtedly exerting a profound influence on the whole situation; again, the " clad " light alloys offer such attractions as coverings in the marine atmosphere of this country. It appears most probable that this method of construction will persist for some time. But the interesting developments in synthetic resins and impregnated woods offer great possibilities and it is quite probable that wooden construction has a decided future. It is general considerations of this nature which have guided the selection for use in this section of certain aircraft as typical examples

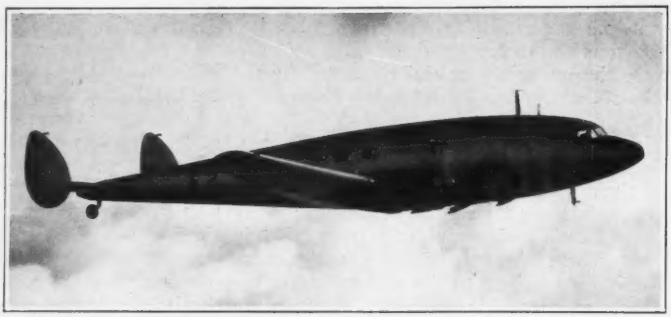


FIG. 2.
The de Havilland " Albatross."

of the construction of 1938, with regard to the use of *materials*, which is the only aspect with which the present paper is concerned. As a general indication of the amount of material involved, a fair estimate of the allocation of weight in a modern civil air liner, having two or four engines, would be:—Power plant 22 per cent., structure weight 35 to 40 per cent., while the remainder is taken up for fuel, oil, equipment, crew and pay-load. Turning to airscrews, a most interesting state of flux exists A great number made of natural wood are flying at the present time, but the need for the variable pitch propeller will probably result in the type becoming entirely obsolescent; steel airscrews are definitely not in the picture; of metal airscrews, probably 98 per cent. are of duralumin, while the magnesium airscrew is being used in increasing numbers; improved woods are coming into extended use and appear to have a most promising future. However, the material of the airscrew is such an important subject that it will receive detailed treatment in a later section.

Fig. 2 shows the de Havilland " Albatross " air liner, having an overall length of 71ft. 6in., a wing span of 105ft. and tare weight of 9.5 tons; the speed of the machine is 210 m.p.h. at 11,000 feet at weak mixture cruising power. It is probably the most perfect example of wooden construction, giving a perfectly smooth surface entirely free from discontinuities. The fuselage shell, which

FIG. 3.

De Havilland "Albatross."
A. Fuselage in construction.
B. Central box of wing.

forms the monocoque structure, consists of an inner and outer layer of stress bearing three plywood, mainly of cedar, separated by a layer (about 1in. thick) of balsa wood, whose function is to stabilise the threeply against buckling under compression. Fig. 3a shows a portion of the fuselage during construction. The wing is built up round a central box of stressed skin construction, the essential features of which are shown in Fig. 3b; two box spars with transverse ribs secured and glued to them, covered top and bottom with spruce planking laid diagonally on longitudinal stringers on top of the ribs, constitute this central box. A final covering of cedar plywood covers the spruce planking. Both casein and synthetic glues are used in the construction.

As a modern example of a large aeroplane, the structure of which, with the exception of a few fittings of stainless steel, is constructed throughout of light alloy, we may glance at the latest Short Empire Flying Boat. Because of the very especial interest taken during the present year in the successful flight of the Short-Mayo " Composite," Fig. 4 is reproduced; the lower component of

FIG. 4.
The Short-Mayo composite aircraft.

that craft is essentially an Empire boat of the type which is to be briefly discussed. The new Short Empire Boat is a four-engined cantilever monoplane having a wing span of 114 feet, a length of 88 feet and weight (empty) of 10.9 tons and a maximum speed, at 5,500 feet, of 200 m.p.h. The essential features of the hull construction—in the region of the front spar hull frame—and of the wing are illustrated sufficiently in Fig. 5. With regard to the materials used, all the structural parts are made of high tensile aluminium alloy sheet in combination with extrusions of RR56 alloy; the junction fittings of wings to hull are stainless steel forgings. The covering generally is of Alclad sheet, joggled and flush riveted to give a smooth surface; the only exceptions to this metal covering being the movable surfaces such as ailerons, elevators, rudders, etc., which are fabric covered to effect saving of weight in these components which must be statically balanced, although even here, the first third of the chord is metal covered. The " clean " design made possible by the use of extrusions and plate is brought out clearly in Fig. 6.

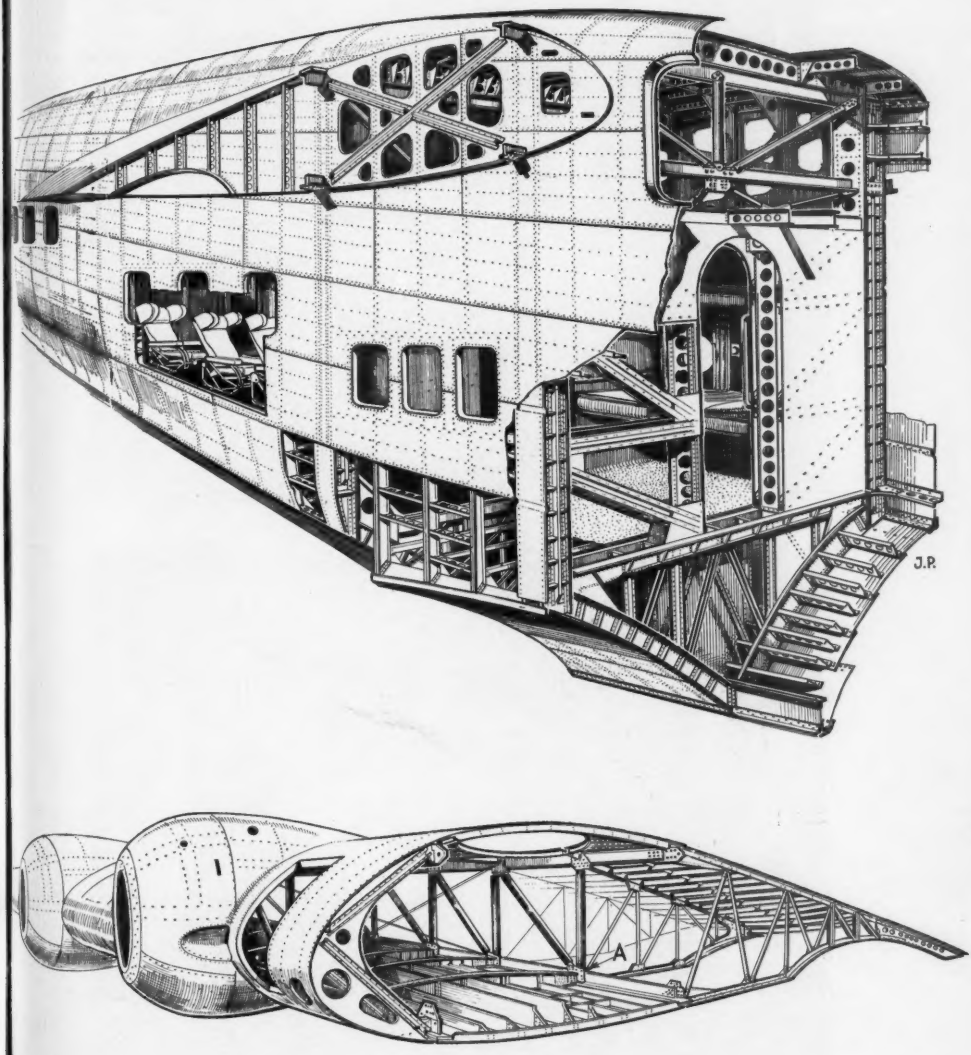


FIG. 5.

The Empire Flying Boat.

Sketches showing features of the construction of the hull and wing.

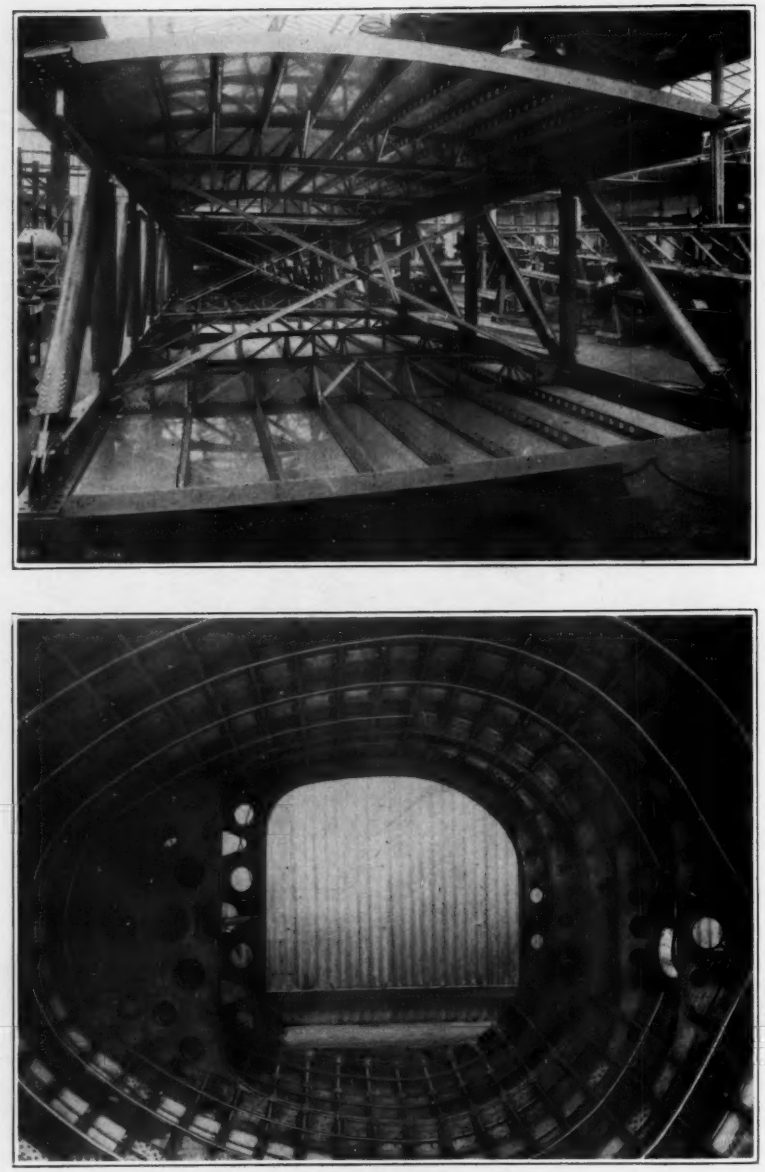


FIG. 6.
The Empire Flying Boat.
Main spar of wing and hull section.

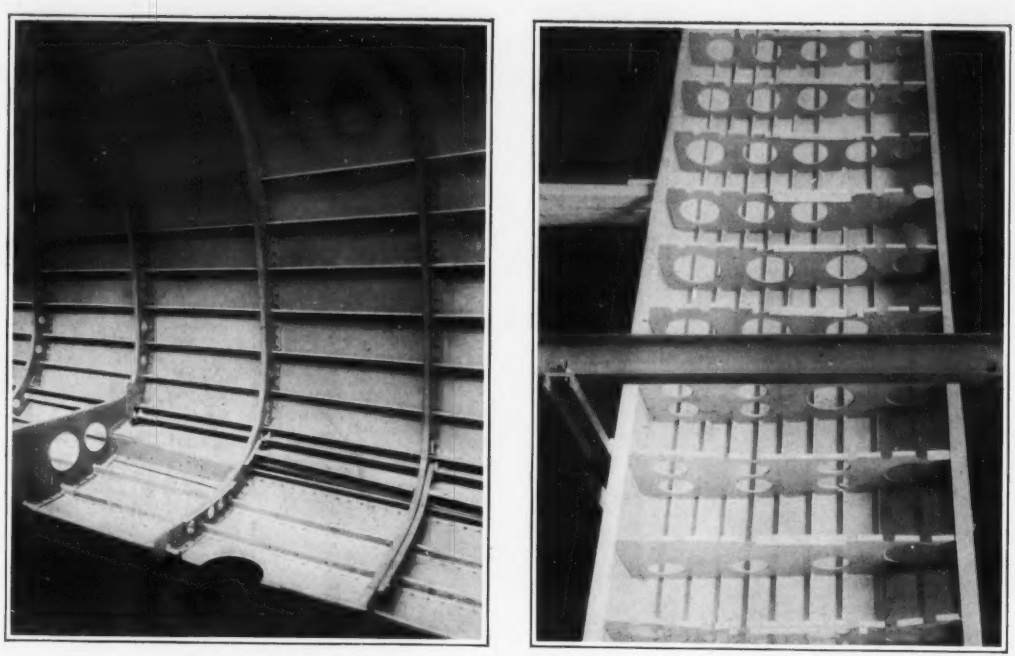
Fig. 7 shows the Fairey " Battle " which may be taken as a very interesting example of composite construction of light alloy and steel. It has a length of 42ft. 2in., a wing span of 54ft., a tare weight of 3 tons, and a speed of 257 m.p.h. at 15,000 feet. The rear portion of the fuselage is semi-monocoque in which the fullest advantage is taken of light alloy plating and extrusions, while the front portion, from airscrew to aft of the cock-pit, is a steel tube girder. Fig. 8a shows some interesting features of the light alloy fuselage construction. The main longeron shown (one of four) is an extruded section of L40, while the fuselage frames are of pressed Z section of duralumin. Of stringers there are none, their place being taken by forming a curled " lip " on one edge of each skin plate, also of duralumin; this is a further example of the new uses of light alloy plating. The wing construction, illustrated in Fig. 8b, is essentially a two-spar structure, with Z section stringers. The built-up main spars are formed of extruded angle sections, these and the extruded stringers being of L40 alloy; the wing skin, also the spar webs are of duralumin. All light alloy parts are protected by anodising and camouflage finish.

FIG. 7.
The Fairey " Battle."

The examples referred to above must suffice as detailed illustrations of modern practice; for further descriptions, the reader may be referred to various publications.[4 5 6 7]

Turning to modern power units, the Bristol " Hercules HE—IM," shown in Fig. 9a, is an outstanding 14-cylinder double-bank radial sleeve valved engine; it has a maximum power rating of 1,375 h.p. at 2,750 r.p.m. at 4,000 feet altitude; the nett dry weight of the engine is 1,640lb. Fig. 9b shows the Bristol " Pegasus XX," having nine cylinders, fitted with poppet valves, it has a maximum power rating of 925 h.p. at 2,600 r.p.m. at 10,000 feet altitude.

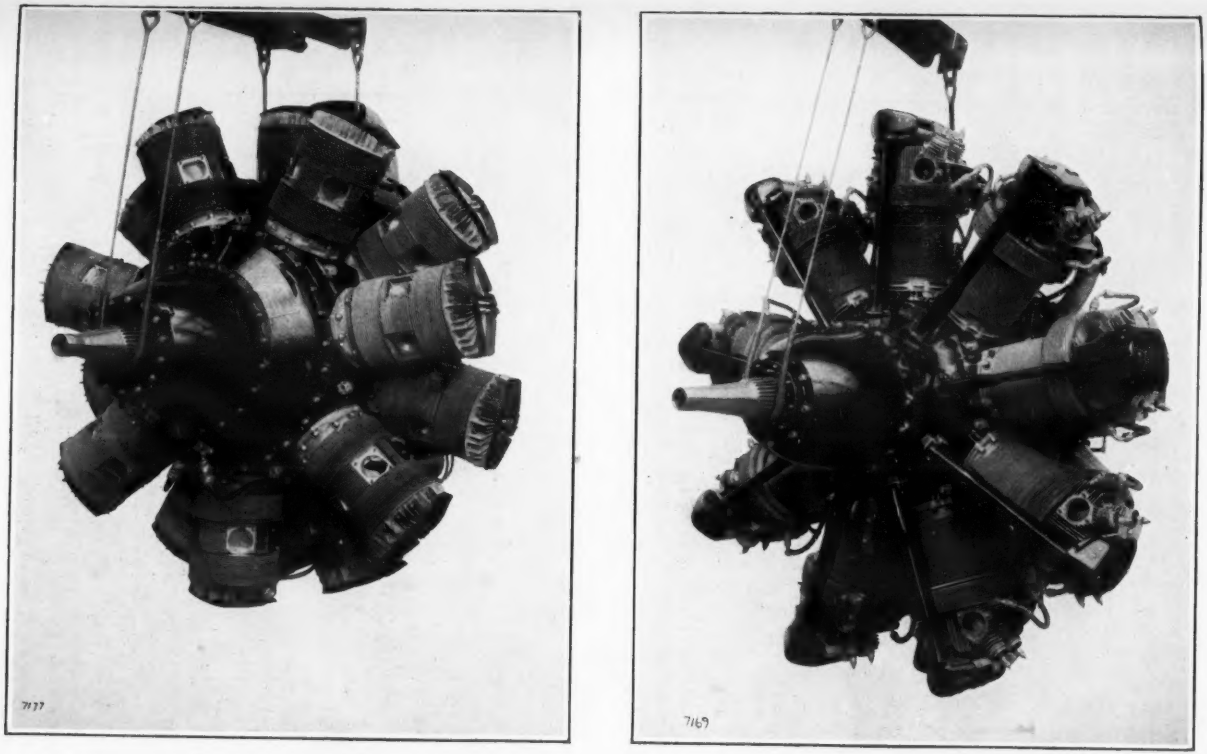
[4] " Modern Tendencies." " Flight," Nov. 25th, 1937.
[5] " Imperial Ensigns." " Flight," Jan. 7th, 1937, also " The Aeroplane," 31st March, 1937.
[6] " A Modern Heavy Bomber." " Flight," Oct. 21st, 1937.
[7] " Metal Construction of Aeroplanes." A. F. Bennell, " The Aeroplane," 15th Dec., 1937.



A B

FIG. 8.

Constructional details of the "Fairey" Battle.
A. Stressed skin fuselage.
B. Wing spar box.

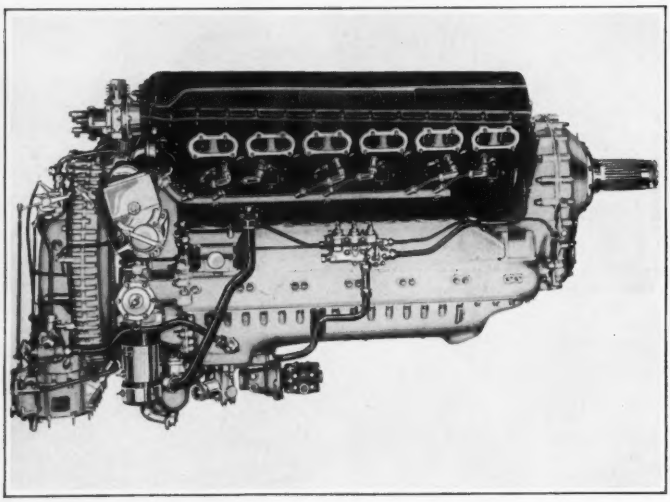


A B

FIG. 9.

A. Bristol "Hercules HE-IM" (sleeve valve).
B. Bristol "Pegasus XX" (poppet valve).

A



B

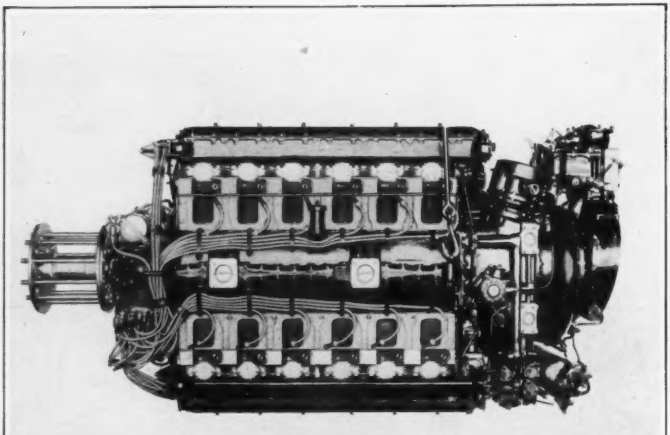


FIG. 10.

A. Rolls-Royce "Merlin II."

B. Napier-Halford "Dagger III."

Fig. 10a shows the Rolls-Royce " Merlin II " engine, a 12-cylinder 60° Vee-type, liquid-cooled, which has a maximum power rating of 1,030 h.p. at 3,000 r.p.m. at 16,250 feet altitude; the dry weight of this engine is 1,340lb. Fig. 10b shows another type of in-line engine, the Napier-Halford " Dagger III "; this is an air-cooled engine, having 24 cylinders, in four blocks of six, arranged in " H " formation; it has a maximum power rating of 805 h.p. at 4,000 r.p.m. at 5,000 feet altitude, the nett dry weight being 1,310lb.

Of what materials are such engines principally constructed? To answer this question fully it would be necessary to present extensive lists and a vast amount of specification data. Of much more interest may be a general analysis of the materials used in regard to broad classifications and principal sub-divisions within each class, and such an analysis is presented in Table II; these data relate to the main engine only, accessories, etc., not being included. It is believed that analyses of this type have not previously been published and, taken in conjunction with the previous information relating to the 1903 Wright engine, may show up in vivid contrast the developments that have taken place in the nature and number of engine materials during the intervening 35 years. The data given, reduced to an even broader type of classification, show that the materials of these engines, on a weight basis, are:—

	A	B	C
Ferrous Metals	42%	48%	48.1%
Non-Ferrous Alloys, Light ...	53.5%	47%	48.3%
Non-Ferrous Alloys, Heavy ...	4%	4.7%	3.4%
Non-Metallic Materials ...	0.5%	0.3%	0.2%

The materials of which the aircraft engine are composed can be regarded as a triumph of metallurgical progress. A few components may be mentioned which represent the results of extensive research devoted to meeting the strenuous working conditions imposed by the engine. Starting with what may be termed the " heart " of the engine, briefly consider the piston, cylinder, valves, connecting rod, bearings and crankshaft. The cylinder head of an air-cooled engine is indeed interesting. It probably consists of a forging of aluminium alloy, specially chosen for heat resistance, heat conductivity and machineability allied with good physical properties; the outside will be cadmium plated. It is fitted with a barrel of Ni-Cr-Mo steel, the inner surface nitrogen hardened to resist wear. The valve seatings are made of a special Ni-Cr-Mn steel whose composition confers an especially high coefficient of expansion, 0.000022, approximately equal to that of the aluminium alloy in which it is fitted, thus overcoming the one time serious problem of maintaining a tight fit; the seat facing is able to resist the demands of impact, wear, erosion and corrosion by the protection afforded by a welded-on ring of " Stellite," an alloy of cobalt, chromium and tungsten. The valve guides will probably be of phosphor bronze, or aluminium bronze. This naturally brings us to the exhaust valve itself which has to perform what is possibly the most severe duty demanded of any component of a high output engine, to the severity of which duty the employment of leaded fuels has so greatly contributed. The hollow body of the valve is an austenitic high nickel and chromium steel, the stem is nitrided, in some cases the valve facing is stellited, while the head is covered with an 80/20 Ni-Cr alloy, of which the valve body itself may, in future, be made; in other cases the 80/20 Ni-Cr alloy is applied both to seat and head; the cavity of the valve is partly filled with sodium to facilitate the conduction of heat from the head to the stem. The piston body is an aluminium alloy forging, although magnesium alloy pistons are being extensively developed and may become the piston of the future provided certain difficulties are overcome. The gudgeon pin is of high strength case-hardened nickel-chrome steel, while the piston ring, a most important component, will be of an alloy cast iron. With regard to the material of the connecting rod, this will depend on the type of engine; to meet the severe service of the radial engine, a high tensile air-hardening nickel-chromium steel, having a tensile

TABLE II.

A GENERAL ANALYSIS OF THE MATERIALS USED IN THREE MODERN AERO ENGINES.

General Classification.	Type.	ENGINE A (Radial Air-Cooled). Number of Materials.	Weight lb.	% of Total Weight of Engine.	ENGINE B (In-line, Liquid-Cooled). Number of Materials.	Weight lb.	% of Total Weight of Engine.	ENGINE C (In-line, Air-Cooled) Number of Materials.	Weight lb.	% of Total Weight of Engine.
Ferrous Metals.	Cast Iron	2	5	0.5	—	—	—	2	2	0.1
	Carbon Steels	9	30	3.0	3	114.5	9.6	20	212	18.2
	Low Alloy Steels—									
	a Nickel	1	60		3	185		2	14	27.6
	b Nickel-Chromium ...	5	180		2	123.5		6	308	
	c Chromium	—	—	29.0	1	9	35.6			
	d Chrom.-Molybdenum	1	50		1	92.5				
	e Chrom.-Vanadium ..	—	—		1	13				
	High Alloy Steels—									
	a Chromium	3	5	9.5	2	9	2.8	10	10	2.2
	b Nickel-Chromium ...	1	90		2	24.5		2	15	
	Aluminium Alloys—									
	a Castings	3	200	50.3	1	440	47	4	221	33.7
	b Forgings, etc. ...	6	303		5	114.5		16	172	
Non-Ferrous Metals.	Magnesium Alloys—									
	a Castings	3	31	3.2	—	—	—	1	168	14.6
	b Forgings, etc. ...	1	1					1	2	
	Copper	1	3	0.3	1	9	0.7	2	1	3.4
	Brass	4	7	0 7	1	4.5	0.3	10	7	
	Bronze	4	30	3.0	3	44	3.7	12	32	
Non-Metallic.	Rubber, Bakelite, etc. ...	—	5	0.5	—	3	0.3	8	3	0.2
	Totals ...	44	1000	100	27	1186	100	96	1167	100

strength of more than 100 tons/in.^{2} is used for the master-rod, while other rods for such an engine, also, the connecting rod for in-line engines, would be a nickel-chromium steel of about 65/75 tons/in.^{2} tensile.

A material used for the crankshafts of both types of engine is a chrome-molybdenum steel, having a tensile strength of 55/65 tons/in.^{2}, nitrided all over. The hardness conferred by such nitriding and the resulting reduced wear is obvious, but a much more interesting point is that a greatly increased fatigue resistance is thus obtained at the regions of stress concentration, such as oil holes, fillets, etc.; reference will be made later to this rather curious result as, at first sight, it would not be expected from the addition of a casing which is very hard and practically devoid of plasticity. The cam shaft and rockers for an in-line engine should also be mentioned as components which must withstand very severe service. Case-hardened 5 per cent. nickel steels are used for the shaft and the rockers, the latter being covered with a thick deposit of chromium on the rubbing face of the rocker pad, representing an expensive but necessary combination. Turning to bearings, it may be said that, in general, lead bronze (on a steel backing) has almost entirely replaced white metal as the bearing material, and is able to meet the duty demanded with some margin for future development; the materials of the delicate floating bushes are a tin-base alloy containing Sb, Cu, Ag, and Ni in conjunction with a backing of a low carbon steel containing silicon and manganese. A suitable material for gears has always been of primary importance to the aero engine and particularly so with the air-screw and supercharger drive; at present, the gear position is regarded as satisfactory, but the demands on this component continue to increase; a typical material of to-day is a case-hardened Ni-Cr steel of 85 tons/in.^{2} tensile strength.

TABLE III.

APPROXIMATE SEQUENCE OF CHANGES, DURING THE PAST 30 YEARS, IN THE MATERIALS USED FOR FOUR IMPORTANT ENGINE COMPONENTS.

Component.	Name or Specification.	Typical Composition.	Approximate Tensile Strength (tons/sq. in.)
Crankshaft	—	0.45 C., 0.6 Mn.	35-40
	—	0.7 C., 0.3 Mn.	45-60
	KE 805	Nickel Chromium Steel	60-70
	B.S.S.11	0.3 C., 3.0 Ni., 0.75 Cr.	55-65
	DTD 228	0.3 C., 1.0 Cr., 1.0 Mo. (Nitrided)	55-65
	DTD 306	0.25 C., 3.0 Cr., 0.5 Mo. (Nitrided)	60-70
Connecting Rods	—	0.45 C., 0.6 Mn.	35-40
	—	0.7 C., 0.3 Mn.	45-55
	KE 805	Nickel Chromium Steel	60-70
	B.S.S.65	0.25 C., 3.0 Ni., 1.2 Cr.	65-70
	B.N.D.	0.3 C., 4.0 Ni., 1.25 Cr.	105 (min.)
Valves*	—	Malleable Cast Iron	—
	Composite	Cast Iron Head and 3% Ni. Steel Stem	—
	Nickel-Chrome	3.0 Ni., 0.5 Cr., 0.35 C.	5.2 at 800°C
	5% Nickel	5.0 Ni., 0.3 Cr., 0.12 C.	5.5 at 800°C
	High Speed Steel	14.7 W., 3.4 Cr., 0.55 C., 0.5 Va.	8.7 at 800°C
	Stainless Steel	13 Cr., 0.3 C.	6.0 at 800°C
	Cobalt Chrome	13 Cr., 1.0 Ni., 5.0 Co., 1.5 C.	10.0 at 800°C
	Silicon-Chrome	9 Cr., 4 Si., 0.45 C.	7.0 at 800°C
	DTD 49B	13 Cr., 13 Ni., 2.5 W., 0.4 C., 1 Si.	20.0 at 800°C
Gears	Case-hardening MS.	0.15 C., 0.6 Mn.	35-45
	KE 805	Nickel Chromium Steel	80-90
	3% Ni. Case-Hardening Steel	3 Ni., 0.12 C.	45-60
	5% Ni. Case-Hardening Steel	5 Ni., 0.12 C.	70-85
	Ni-Cr. Case-Hardening Steel	4.25 Ni, 1.3 Cr., 0.12 C.	85-95

* Improvements in corrosion-resistance and strength at elevated temperatures.

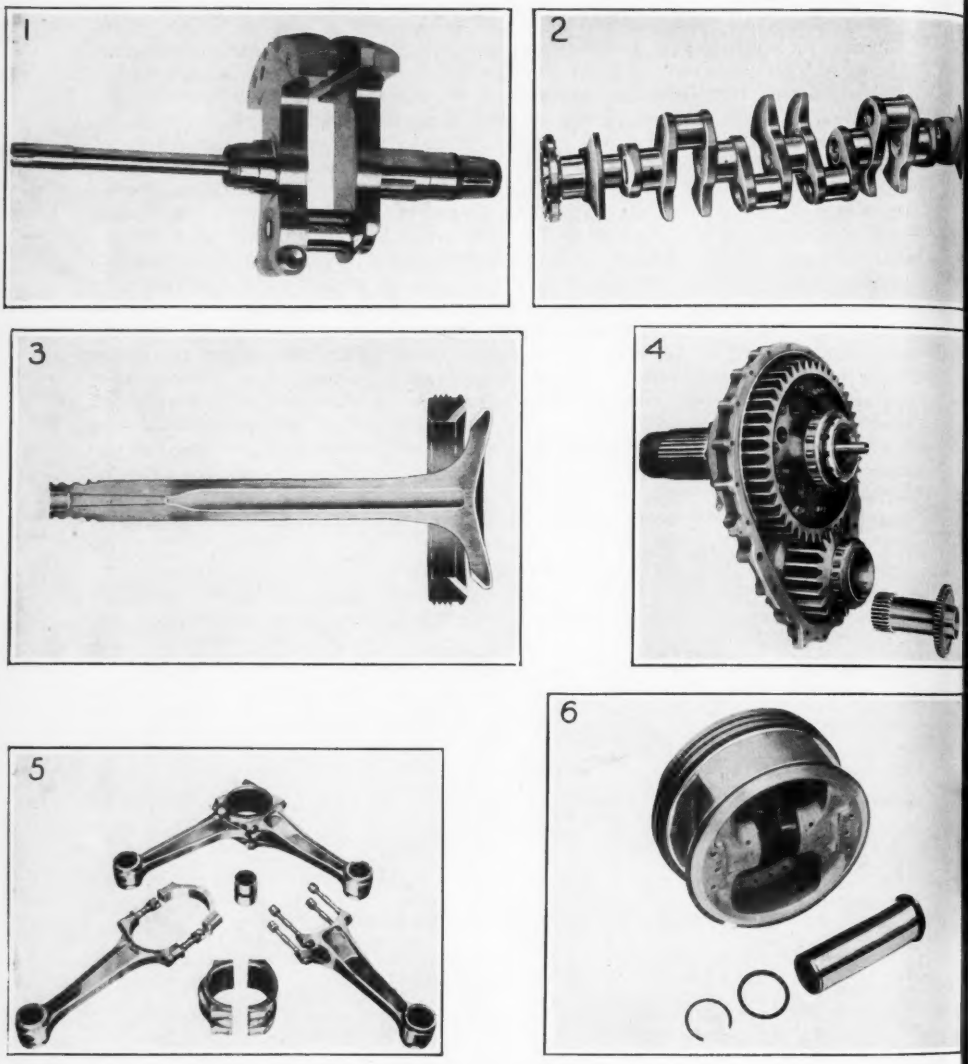


FIG. 11.

1-2. *Nitrided steel crankshafts.*
3. *Sodium-cooled exhaust valve and insert: Nitrided stem, stellited seatings, head covered with 80/20 Ni. Cr. Alloy.*
4. *Reduction gear assembly in cast aluminium alloy casing.*
5. *Connecting rod and bearing assembly.*
6. *Forged aluminium alloy piston, steel gudgeon pin, etc.*

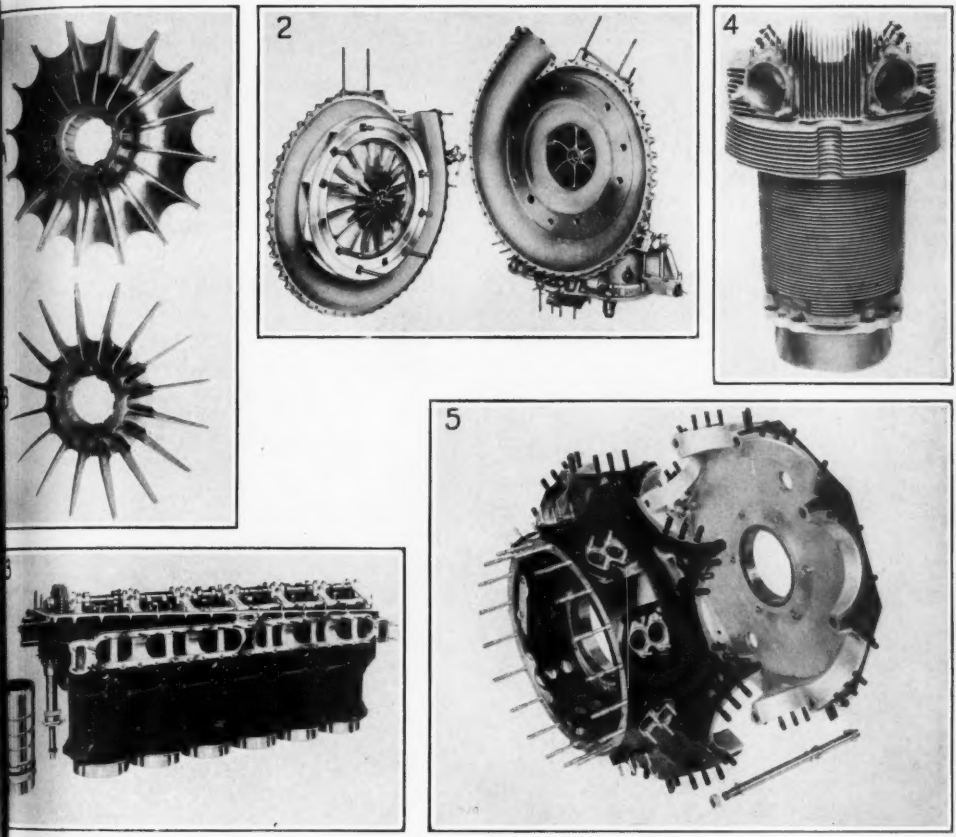


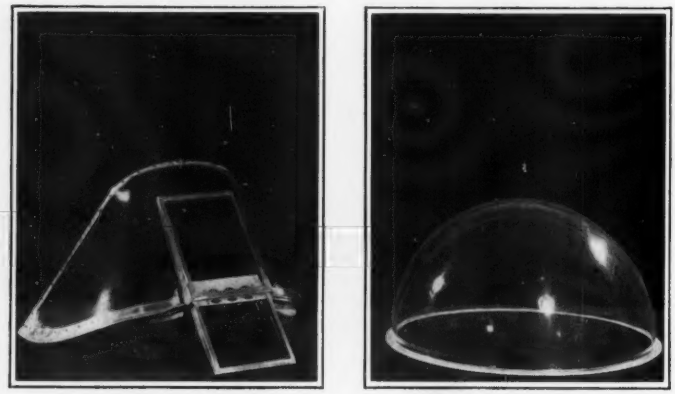
FIG. 12.

1. *Supercharger impellor*: (*A*) *Aluminium alloy.* (*B*) *Steel.*
2. *Supercharger assembly*: *Casing of cast aluminium alloy.*
3. *Cast aluminium alloy cylinder block (with camshaft drive and valve mechanism in position; liner detached).*
4. *Forged aluminium alloy cylinder head.*
5. *Forged aluminium alloy crankcase.*

Crankshafts, connecting rods, valves and gears may be used as typical illustrations of the constant efforts made to devise improved materials to meet increasing severity conditions; in this connection, it may be of interest to indicate the changes which have taken place, during the last 30 years, in the materials used for these components; these are summarised in Table 3.

The supercharger impeller is a noteworthy component as it may revolve at 24,000 r.p.m., while, in addition to the centrifugal stresses, is subject to vibration and flutter; it is sometimes made of a 55-ton nickel-chromium steel while, in other cases, successful use has been made of a 27-ton high grade wrought aluminium alloy. Although of relatively small size, the sparking plug is a vital component of the engine and a most important development is the form in which the negative points are made of platinum or platinum-iridium wires placed radially; this interesting component has been fully described alsewhere.[8]

Turning to other outstanding engine components made of light alloy, we may recall the large cylinder block and crankcases, also various casings in cast aluminium alloy for the in-line engine, and the intricate forging, of the improved " duralumin " type of alloy, used for the front and rear crankcases of a radial



Windscreen (with laminated glass sighting insertion). *Turret hemisphere.*

FIG. 13.

Articles made of transparent synthetic resin.

engine. Magnesium alloys already find many uses in some engines; as an outstanding example, mention may be made of the cast crankcase used in a leading in-line engine, where a Mg. alloy containing 8½ per cent. Al., 3½ per cent. Zn. is employed. For the special conditions in exhaust manifolds and silencers a special Ni.-Cr.-Fe. alloy, having a high nickel content, is coming into use; it is especially suitable because of its combination of strength, toughness and ductility coupled with resistance to heat and corrosive influences. As shown in Table II, the total number of materials used in the engine are very extensive, but the few examples quoted above must suffice for special mention; some typical engine components are illustrated in Figs. 11 and 12.

A typical landing gear represents many interesting uses of ferrous and non-ferrous metals of which perhaps special mention may be made of the wide use of magnesium-rich alloys, containing aluminium and zinc, for such purposes, in the *cast* condition, as the wheel, control valves, undercarriage bracing members, etc., and in the *forged* condition for those components subjected to hydraulic

[8] " Metallurgy and the Aero-Engine." D. R. Pye, Jour. Inst. Met., Vol. 4, Pt. 9, Sept., 1937.

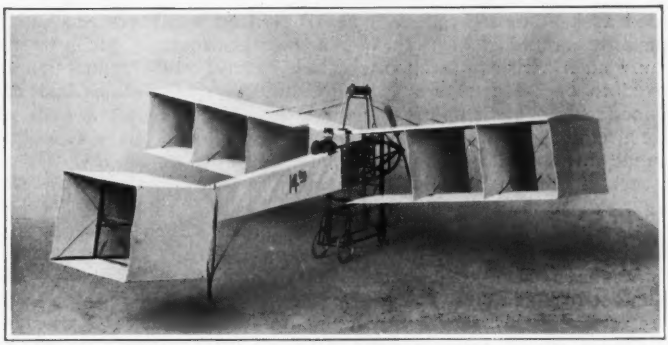


FIG. 14.
The Santos-Dumont Aeroplane of 1906.

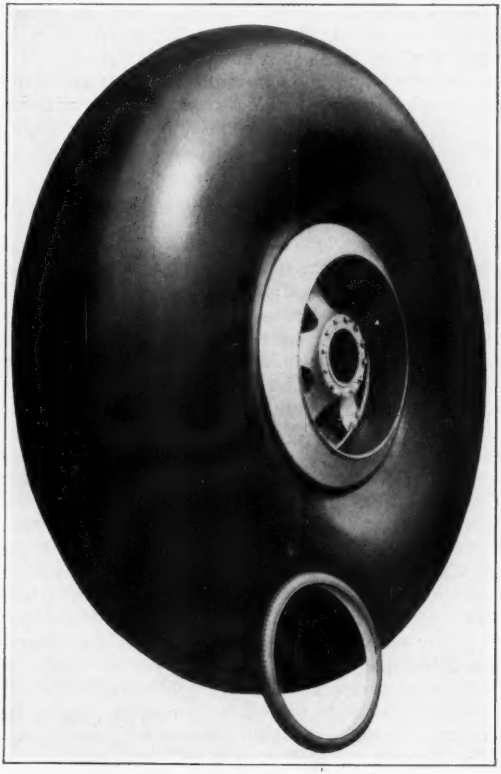


FIG. 15.
A landing wheel of 1938.

pressure. The development of " conducting " rubber for landing wheels must be regarded as a noteworthy achievement. Synthetic rubbers find in aircraft a use for piston cups and gland rings of the hydraulic units in which engine-driven pumps cause such a rise of temperature that natural rubber and other materials have proved to be quite unsuitable; also, natural rubber is useless in contact with the non-freezing oils employed in this gear. Other synthetic materials, such as reinforced resins, are used for various purposes, but perhaps especial mention may be made in this section of the extensive use of a transparent thermo-plastic resin for cockpit coverings, retractable turrets, etc.; typical examples are shown in Fig. 13.

This section may, perhaps, fittingly be concluded with a reference to the tyre of the landing wheel, a most important component and one in which marked developments have been made both in quality and size. Fig. 14 shows the Santos-Dumont machine of 1906 which made the first public flight in Europe and was, therefore, probably the first machine to be fitted with a wheeled undercarriage. These wheels were of the ordinary cycle type, as used nowadays as the front wheel of carrier cycles. Fig. 15 shows a 6ft. 4½in. diameter tyre of to-day, photographed side by side with a 14in. diameter cycle tyre which has been chosen as probably very similar to that used by Santos-Dumont. The total weight of the 1906 machine was 350lb.; the modern *tyre* of Fig. 15 weighs 379lb., the complete wheel amounting to about 650lb.

The foregoing brief glance at the variety and nature of some of the materials which are now available may suffice to recall the contributions made by the metallurgist, chemist and physicist which, allied to the skill of the engineer and the daring of the aviator, have made possible the aircraft of 1938.

In the following section more detailed consideration will be given to these materials.

Part III.

Technical Survey of the Aircraft Materials.

A. Metals and Alloys.

The first impression gained from a survey of the metals and alloys available for aircraft purposes in 1938 is one of admiration for what has been accomplished, followed immediately by a realisation of the immense possibilities that remain for future research and development. Pure metals do not find much use for aircraft purposes, yet, as bases for practical alloys, their intrinsic properties are of fundamental interest; strange as it may seem, it is only comparatively recently that any degree of success has been obtained in isolating a few metals in a high state of purity and determining their physical properties, thus making a first step in a fundamental aspect of scientific metallurgy. The difficulties involved in making a general systematic study of metallic alloys are stupendous in view of the possible combinations. For example, assume that an attempt was made to study, scientifically, say, 37 metals or metalloids; these alone would provide 666, 7,770 and 66,045 binary, ternary and quaternary systems, respectively; many useful commercial alloys contain more than four essential metallic constituents. For a most interesting discussion of this general problem in relation to alloy steels, reference may be made to the First Report[9] of the Alloy Steels Research Committee. Before any alloy system can be properly understood, its equilibrium diagram should be determined, hence, every encouragement should be given to the establishment of these primary foundations of metallurgical knowledge. The usual method employed is that of taking heating and, especially, cooling curves at very different rates, coupled with examination of microstructures. The more recent X-ray method gives a rapid means of surveying an alloy system, the number of alloys needed to map out the fields in the equilibrium diagram being much smaller than by the thermal or microscopical method; useful prediction is

[9] Special Report No. 14 of the Iron and Steel Institute, 1936.

likely to arise from the examination of the complete crystal structure of a phase (a much more complex matter than the taking of ordinary X-ray photographs) and when a phase is found, having a similar arrangement of atoms to that already determined in a previous system, similar properties may be expected. But all such methods are necessarily laborious and time-consuming, and rich rewards may result from the steady pursuit of what are often referred to somewhat scornfully and most unfairly, as the " hit and miss " methods of making a quick survey of an alloy system by determining the physical properties of a number of compositions covering what appears to be an attractive field. In fact, in the history of metallic alloys, most of the real landmarks relate to discoveries obtained before modern scientific methods were even available; for example, we may recall, in connection with the alloy steels, the work of Stoddart and Faraday, in 1821, which started the history of alloy steels, Mushet's 7-12 per cent. tungsten tool steel of 1857, the first chromium steel made by Bauer in 1865-69, Hadfield's 12 per cent. manganese steel of 1882, Marbeau's 3-5 per cent. nickel steel of 1889, the development of the nickel-chromium steels about 1890, also, that vanadium steels were produced, in Austria, before 1899; similarly, notable " discoveries " have been made both in the light and heavy non-ferrous groups.

In addition to future possibilities of radically new alloys, much development is likely to result by the improvement of existing alloys by relatively small alterations in composition, by suitable heat treatment and by refinement of methods of manufacture. Taking the alloy steels again as an example, their strength, resistance to creep, and many other properties, depend largely on the distribution of the alloying elements between the iron and the carbon and on the arrangement of the carbide particles, while further work on the effects of small quantities of other elements, on such properties as temper brittleness and inter-crystalline attack is well worth while.

It is most probable that the future will disclose great developments that may amount almost to a revolution in metallurgy, *i.e.*, the production of alloys by the sintering of powders. A most interesting recent development of a heavy alloy will be referred to later in some detail; carbide cutting tools and some bearing metals are already prepared in this way. The method has great general possibilities of affording a small grain size, freedom from segregation, and " graded " properties: one can visualise, *e.g.*, an engine liner having the required bearing properties at the surface and, also, those " joining " properties so desirable at the junction to the steel or other backing material.

1. Steels.

In addition to carbon—the essential element which modifies the properties of iron and converts it into steel—the most important alloying elements used in aircraft steels are nine in number, *i.e.*, nickel, chromium, molybdenum, tungsten, vanadium, manganese; titanium, cobalt and silicon, of which the six first named are especially valuable. These aircraft steels are covered, at the time of writing, by no less than 90 specifications, relating to materials which vary widely in composition, mechanical and physical properties; for summary purposes, they may, perhaps, be considered as falling into some three broad main groups and about 17 types, based on essential composition, as follows:—

Carbon Steels	Mild Steels (C. $\gtrsim$0.35%)
	Medium Carbon Steels (0.35/0.45%C.)
	Higher Carbon Steels (0.4/1.0%C.)
Low Alloy Steels	Manganese Steels (1½% Mn.)
	Nickel Steels (3/5% Ni.)
	Nickel Chromium Steels, with small additions (Ni. 3/5%, Cr. 0.5/1.6%)
	Chrome-Molybdenum Steels (Cr. 0.5/3.5%, Mo. 0.15/1.5%)
	Chrome-Vanadium Steels (Cr. 1.0/1.5%, V. $\gtrsim$0.25%)
	Silico-Manganese Steels (Si. 1.6/2.1%, Mn. 0.8/1.3%)
	Chrome-Aluminium Steels (Cr. 1.4/1.8%, Al. 0.9/1.3%)

High Alloy Steels
- Special Alloy Steels (Ni. ⩾1.0%, Cr. 3½/14%, V. ⩾1%, Mo. ½/1%, W. 14%+, Co. 3/5%)
- Manganese Steels (Mn. 11%+)
- High Chromium, low carbon (Cr. 12+%, C. 0%/.15%)
- High Chromium, medium carbon (Cr. 12+%, C. .15/.35%)
- High Chromium, low nickel (Cr. 16/20%, Ni. 1/3%)
- Austenitic Chrome-Nickel (Cr. 12+%, Ni. 6+%)
- Austenitic Chrome-Nickel Tungsten (Cr. 12+%, Ni. 9+%, W. 0/6%)

To render such a broad classification of practical value it should be supplemented by tables giving detailed analyses, heat treatments, mechanical properties and list of aircraft applications; such detailed data have been presented by Hatfield.[10]

Glancing over the present position in general, carbon steels with carbon content ranging from 0.05 to 0.85 per cent. are still employed. The low carbon type has the advantage of being most readily welded and can also be easily fabricated into forms suitable for lightly stressed parts.

Where a high fatigue strength allied with substantial ductility is required, this is achieved by the addition of special elements which facilitate the proper hardening of the steel and enable a uniform and homogeneous structure to be obtained on subsequent tempering. In this category of low alloy steels, we find the use of 3 per cent. or 5 per cent. of nickel with or without the addition of up to 1½ per cent. of chromium, or the addition of other elements such as molybdenum, vanadium or tungsten. The outstanding high tensile steel is one containing about 3 per cent. of nickel, 1.0 per cent. of chromium, molybdenum 0.5 per cent., vanadium 0.2 per cent., and it is interesting to consider why these various elements are incorporated. The nickel, together with the added chromium, facilitates hardening of the steel, the molybdenum tends to ensure the maintenance of a high notched bar impact value, whilst the vanadium confers a fine-grained structure regarded by many as an advantage in such material. Such a typical alloy steel, in the hardened and tempered condition, may have a 0.1 per cent. proof stress in excess of 60 tons/sq. in., an ultimate tensile strength up to 75 tons/sq. in., good ductility (over 16 per cent.) and notched bar value[11] (over 40ft. lb. Izod). Many parts demand great surface hardness, and this may be achieved either by case-hardening, nitriding, or by using the air-hardening type of steel. For case-hardening where a strong core is required, a high nickel content is used up to 5 per cent. with or without chromium, and for effective air-hardening properties for use in parts such as gears, a nickel content of something over 4 per cent. with a chromium content approximating to 1½ per cent. and a carbon content of the order of 0.3 per cent. is found most effective.

In the foregoing words can the present position as regards the low alloyed high tensile steels be summarised, but it is necessary to add that of late some considerable use has been found for carbon steels in which the manganese content has been increased up to 1½ to 2 per cent. For the production of the parts of ball bearings, that is for the balls and for the races, a chromium steel containing towards 1.5 per cent. of chromium, along with a high carbon content in the neighbourhood of 0.9 to 1.0 per cent. still holds the field, whilst with regard to springs, alloy steels based on the addition of chromium or manganese with or without vanadium and silicon provide in the hardened and lightly tempered condition, the necessary hardness and high fatigue resistance.

So far mention has been made of the increase in the strength of steels obtained by means of the addition of special elements and heat treatment, but no discus-

[10] "Ferrous Metallurgy in relation to Aircraft." W. H. Hatfield, Jour. Roy. Aero. Soc., 1935.

[11] It may be pointed out, in passing, that a most valuable survey of the present position of the notched bar test was made in a recent discussion, organised by the Joint Committee on Materials and their Testing, in collaboration with the Manchester Association of Engineers; see Trans. Man. Assoc. Engrs., October, 1937, Vol. 1937/38.

sion of materials available in aircraft design would be complete without some reference to the great utility and success of the use of cold-working effects. Whether it be in the production of strip or of wire, the effect of reduction in section by cold-working in raising the hardness and strength of the material makes available properties not obtainable in any other manner. For instance, carbon steel spring wire, streamline sections, alloy steel strip (rustless and otherwise) are materials which are dependent for their properties upon the utilisation of some of the plastic deformation in the formation of the final section. Modern theory, based on recent scientific investigation, fully confirms the efficacy of this procedure.

Turning now to the more specialised steels in which the alloying metals are added in greater quantities, mention may be made of some of the outstanding materials. There is now available a large range of high chromium and chromium-nickel steels having especially high resistance to corrosion. The well-known rustless steels were based on a chromium content of 12-14 per cent.; in this series the carbon content varied from under 0.10 per cent.—in the case of steels of desired low tensile strength—up to 0.3-0.4 per cent. C. where, as a result of hardening and tempering, a high tensile condition was desired; these steels are still used. A great impetus was given to the use of rustless steel when the austenitic type of material came along, in which a substantial proportion of nickel, 8 to 10 per cent., is used in conjunction with a chromium content of the order of 17 to 20 per cent. Such steels, together with some of intermediate composition, provide all that is necessary for the construction of parts subjected to corrosive conditions; small additions of titanium, molybdenum, etc., prevent intercrystalline attack. An allied class of steels is that used for exhaust valves, but here it is found that the addition of tungsten to the high chromium-nickel content is an advantage, together with an increase in carbon content. Such materials exhibit a high resistance to oxidation and scaling, also, a greatly enhanced strength at the high operating temperatures. This field of heat resisting steels is an especially interesting one, and there is evidence to show that great progress is being and will continue to be made. An extensive survey of this field has been made[12] very recently.

No survey of steels available would be complete without mention of those which can be given an intensely hard surface by heating at temperatures as low as 500°C. in an atmosphere of ammonia. These steels are characterised as nitriding steels, but cover quite a substantial range of composition. Where the steel is required to have the most intense hardness of surface it usually contains 1 to 1½ per cent. of chromium, and about 1 per cent. of aluminium, whilst for surfaces of relatively lower, but still very great, hardness, such steels as the 2 to 3 per cent. chromium steels, to which either molybdenum or vanadium addition has been made, prove most effective.

As one very interesting instance in the development of materials for aircraft, mention may be made of the need, for valve inserts, of a steel having a coefficient of expansion approximating to that of the aluminium alloys. Investigation showed that a steel containing about 12 per cent. of nickel, 3 to 4 per cent. of chromium and about 5 per cent. of manganese, had a suitable coefficient of expansion, 0.000022; it was immediately and successfully adopted for the required purpose. This is one of those instances where the requirements of design, when properly expressed, receive an adequate and immediate answer from the metallurgist. It is understood that a steel has now been produced having a coefficient of expansion as high as 0.000029; suggestions for engineering applications of this steel are awaited by the producers. Although used to a very small extent, it might be worth while mentioning the very interesting 12 per cent. manganese steel with its non-magnetic wear-resisting properties. This particular steel, developed many years ago by Sir Robert Hadfield, is an outstanding instance of the properties of steel being completely modified by the alloy additions.

---

[12] "Heat-Resisting Steels." W. H. Hatfield, Jour. Inst. Fuel, March, 1938.

A need has been expressed for a steel having a tensile strength of about 150 tons/inch^2 for aero engine connecting rods; the development of such a steel has recently been announced.[13] It is described as a Ni.-Cr.-Mo.-V. steel, in the oil-hardened and tempered condition; specimens gave the following mechanical properties:—U.T.S. 149-153 tons/in.^{2}, elong. 9-10 per cent., reduction of area 15-18 per cent., Izod value 8-12ft. lb., with Wohler fatigue ranges of ± 57 tons/in.^{2} (plain) and ± 28.5 tons/in.^{2} (notched). This material is another example of the response of the steel maker to the needs of the aircraft industry.

There are certain properties of steel which vary but little over the whole range of composition; for example, the specific gravity of the available steels falls between the limits of about $7\frac{7}{8}$, while the value of the modulus of elasticity (E) varies between 12,500 and 13,500 tons/inch^2. For certain purposes, a steel having a much higher specific gravity would find uses and it may be mentioned that a high density, machineable, casting alloy, having a specific gravity exceeding 10, has recently been developed.

The science and technique of permanent magnets is a subject in itself, but here tremendous progress has been made in the development of the rich cobalt and nickel-aluminium alloys with iron, resulting in a coercive force undreamt of a decade or two ago.

A survey of the foregoing observations makes it quite clear that steel as originally understood is now available with many diverse characteristics induced by the alloying of other elements and by suitable heat treatment. Metallurgical research has been responsible for the introduction of steels which are magnetic or non-magnetic as desired, which are rustless, and which have a most surprising degree of hardness. Clearly, the future of steel, in competition with other metals for aircraft purposes, will be determined by the properties which can be progressively induced in the future, but the record of the past gives substantial indication that marked further progress may be expected.

2. Alloys of the Light Metals.

The essential requirements of aircraft construction have led to intensive studies of the alloys of the light metals. Metals of the alkali and alkaline earths are chemically far too reactive to be used for constructional purposes, leaving for practical consideration only three metals, aluminium, magnesium and beryllium, having densities of 2.7, 1.74 and 1.83 respectively. Beryllium, once considered so full of promise, has proved extremely disappointing; in spite of extensive research, industrial alloys are practically limited to copper-rich and nickel-rich alloys containing only about 3 per cent. of beryllium and cannot therefore be classed as light alloys. At the present time, therefore, we are left with alloys of aluminium and of magnesium.

The use of aluminium in the comparatively pure state is of fairly long standing. It possesses high resistance to corrosion, when in a high degree of purity; an unexpected property which was only accounted for when the nature of, and protection afforded by, thin oxide films were discovered. Pure aluminium has only a low mechanical strength, even after cold rolling and its most extensive present aircraft use is a covering for composite sheet, where it finds most valuable applications. Although aluminium alloys of various types had previously been developed and were in commercial use, the first strong light alloy appeared with the introduction of duralumin by Wilm in 1908; it opened up the widest possibilities for the use and development of light alloys in general. Consisting essentially of aluminium alloyed with copper and magnesium with the addition of small quantities of manganese, the result was a material which, with special heat-treatment, had mechanical properties approaching those of steel. It was also the first of the " age-hardening " alloys, the properties of which may be made to vary

[13] " Special Steels and their application to Engineering and Shipbuilding." T. Swinden. Proc. N.E. Coast Inst. Engrs. and Shipbldrs., Feb., 1938.

over a wide range with heat-treatment, with or without cold working. The development of other valuable aluminium alloys soon followed, but the discovery of duralumin must always rank as one of the most significant in the metallurgical field. Another notable landmark was the introduction in 1920, by Pacz, of the process of " modifying " cast alloys, using an alloy containing 13 per cent. of silicon. The modification consists in adding a very small quantity of a substance, usually sodium, which changes the structure from coarse to fine; thereby, the eutectic composition is displaced. The subsequent developments are too involved to be followed in the space available; a great variety of aluminium alloys can now be obtained. It may be remarked, however, that, in general, there are three ways in which a soft metal, such as aluminium, may be made stronger by alloying. The added element may enter into solid solution, or it may give rise to a second phase which, suitably distributed through the metal, forms a rigid skeleton, or it may allow the precipitation of ultramicroscopic particles in the course of heat-treatment, producing " age-hardening." The first of these methods has its application in the series of wrought aluminium-magnesium alloys; the second kind of hardening is found in the casting alloys, while the third is the most important. The most valuable alloying systems are as follows:—

Al-Cu. (Cu. up to 9%)
Al-Cu-Mg. (Cu. 4%, Mg. up to 2%)
Al-Cu-Mg-Si. (Cu. 4%, Mg. 2%, Si. 1.5%)
Al-Cu-Ni. (Cu. 4%, Ni. 2%, with additions of Mg. and Si.)
Al-Mg. (Mg. 5/10%, with additions of Mn.)
Al-Mn. (Mn. up to 2%)
Al-Si. (Si. 8/13%, with additions of Mg., Mn. or Co.)

Magnesium is too weak a metal to be used in the unalloyed state and the metals which may be added to it to produce strong alloys are very limited in number. Magnesium alloys, containing Al. and Zn. as essential constituents, were first developed, in Germany, during the period 1908-1920, under the name of elektron, still used as the trade name for alloys made under licence. The possibilities of added alloying elements are still being vigorously pursued; the binary alloys, other than those with Al. do not, as yet, offer great advantages, and the ternary systems are being studied systematically. The following systems have been investigated to some extent with various degrees of success:—

Mg-Mn. (Mn. 2½% max.)
Mg-Al. (Al. 8/12%)
Mg-Ce. (Ce. 10%, with or without additions of Co. and Mn.)
Mg-Al-Ag. (Al. 7½/8½%, Ag. 2½/3%, with additions of Zn., Mn. and Co.)
Mg-Al-Zn. (Al. up to 11%, Zn. up to 3½%)
Mg-Al-Cd. (Al. 8%, Cd. 8%)
Mg-Cd. (Cd. up to 20%)
Mg-Cd-Zn. (Cd. 4%, Zn. 4%)

Magnesium alloys present difficulties in working processes, arising from the hexagonal crystal structure, tending to produce marked directional properties; the structure easily twins, however, and this has led to special processes of manufacture where, by repeatedly changing the direction of stress, the structure can be broken down, affording increased general ductility. Two factors have tended to retard the development of magnesium alloys for aircraft and other purposes, inflammability and low resistance to corrosion, both intrinsic disadvantages of magnesium. But opinion appears to be divided on the increased fire risks attached to the use of magnesium alloys in aircraft. Where thick sections are employed, the fire risk may be considered as negligible; this is borne out by actual engine experience and there is little doubt that the fire risk has been overemphasised in the past. Magnesium alloys must be regarded as readily corrodible. No addition of an alloying metal, in reasonable quantities, has yet been found to inhibit corrosion, although the addition of small quantities of manganese is known to be favourable. But the resistance to corrosion is actually greater than might be expected. Methods of protection by forming an adherent protective layer, united chemically to the metal, have been devised and are referred to in a later section. Experiments on the anodic protection of magnesium

alloys are reported from Germany and America. The development of alloys having improved intrinsic resistance to corrosion is probably the most valuable field of research that can be attacked. For further information concerning the general subject of the light alloys of aluminium and magnesium, reference may be made to papers by Aitchison,[14] Desch,[15 16 17] also Haughton and Prytherch.[18] Attention is also directed to a most valuable survey, by Bucknall,[19] of the progress made in metallurgical research during 1937, in which reference is made to many aspects concerning the light alloys.

Consideration will now be given to the light alloys which are commercially available for aircraft purposes; as some time has elapsed since the position was reviewed, by Aitchison in 1934, and much development has since taken place, it may be useful if rather more attention to detail is given than in the preceding section dealing with ferrous alloys.

(*a*) Aluminium Alloys.

The principle of heat-treatment discovered by Alfred Wilm has had a marked influence on the development of light alloy manufacture. It is well known that the precipitation at room temperatures and at elevated temperatures of a dissolved constituent causes marked hardening in many aluminium alloys. Since Wilm's time, many alloys, other than the original duralumin, have been developed, and these alloys may be considered in the three classes of (1) heat-treatable alloys containing copper and magnesium, (2) heat-treatable alloys not containing copper, and (3) non-heat-treatable alloys, under the main groupings of *wrought* and *cast* alloys.

It will be appreciated that the "texture" of the alloy has a great influence on the heat-treatment reaction, in that wrought alloys have a much greater reactivity than cast alloys, the consequence being that heat-treatment times for cast alloys are considerably longer than those which apply for wrought alloys. On a basis of the above classification, the principal alloys may be discussed.

Wrought Aluminium Alloys.

(1) Heat-Treatable Alloys Containing Copper and Magnesium.

(*a*) To this class belongs the group of alloys of the duralumin type; a typical composition is:—

Cu. 4.2 per cent., Mn. 0.6 per cent., Mg. 0.5 per cent., Fe. 0.4 per cent., Si. 0.4 per cent.

It is heat-treated by quenching in cold water from 480/500°C. and aged at room temperature. The composition quoted is a nominal one, and the alloy, which is obtainable in the form of sheet, strip, tube, bar, extruded section, wire, rivets, forgings, stampings, has the following minimum mechanical properties:— 0.1 per cent. proof stress 15 tons/in.^{2}, U.T.S. 25 tons/in.^{2}, elong. 15 per cent. This alloy is covered by numerous specifications.

(*b*) There have been many logical developments of duralumin, the most important among which has been that of an alloy containing about 1½ per cent. of magnesium. This alloy responds to a precisely similar type of treatment as ordinary duralumin, but has the advantage of increased strength. It is also available in the same forms as duralumin and its minimum properties are:— 0.1 per cent. proof stress 17.5 tons/in.^{2}, U.T.S. 28 tons/in.^{2}, elong. 15 per cent.

[14] "Light Alloys for Aeronautical Purposes." L. Aitchison, Jour. Roy. Aero. Soc., 1934.
[15] "Alloys of the Light Metals." C. H. Desch, Jour. Soc. Chem. Ind., March, 1938, Vol. 57, pp. 69/75.
[16] "Magnesium Alloys." C. H. Desch, Jour. Roy. Aero. Soc., Vol. XLI, No. 317, May, 1937.
[17] "Age-Hardening Alloys." C. H. Desch, Proc. Phys. Soc., Vol. 49 Extra part, p. 103, 1937.
[18] "Magnesium and its Alloys." J. L. Haughton and W. E. Prytherch, H.M.S.O., 1937.
[19] "Research Progress in 1937." E. H. Bucknall, Metal Industry, Vol. 52, No. 1, Jan. 7, 1938.

A recent development of this alloy has been in the production of thick-walled tubes, also tubes of all sizes, which are given a certain measure of cold work after heat-treatment. The properties of these tubes are remarkable, being as follows :—

0.1 per cent. proof stress 22 tons/in.^{2}, U.T.S. 29 tons/in.^{2}, elong. 10 per cent.

(*c*) A further development has been that of alloys of the " super-duralumin " type, in which silicon up to about 1 per cent. is added to an alloy of the normal duralumin composition. This alloy responds after solution treatment to a precipitation heat treatment; after quenching from a temperature of 520° and ageing at 165°C., really remarkable properties may be obtained. As an example may be cited an alloy of the following composition :—

Cu. 3.5 per cent., Fe. 0.75 per cent., Si. 1 per cent., Mn. 0.75 per cent., Mg. 0.75 per cent.

It gives the following *minimum* properties :—

0.1 per cent. proof stress 24 tons/in.^{2}, U.T.S. 30 tons/in.^{2}, elong. 8 per cent.

This alloy is used in the form of extruded sections, and will doubtless find many applications in modern aircraft design.

(*d*) To this class also belong the " RR " alloys; in the wrought class, RR56 is the most used, having the following composition :—

Cu. 1.5-2.5 per cent., Ni. 0.5-1.5 per cent., Mg. 0.6-1.2 per cent., Fe. 0.8-1.5 per cent., Si. $\geqslant$ 1 per cent., Ti. $\geqslant$ 0.2 per cent.

This alloy is available in all the usual forms; in sheet and strip form, however, it is somewhat liable to corrosion. After quenching from a temperature of 530°C., and ageing at 175°C., this alloy gives the following minimum properties :—

0.1 per cent. proof stress 21 tons/in.^{2}, U.T.S. 27 tons/in.^{2}, elong. 10 per cent.

Mention must be made of an alloy, falling into this group, which has been very recently produced, on a commercial basis, and gives mechanical properties which are quite outstanding for an aluminium alloy having a specific gravity of 2.8. Its chemical composition is :—

Cu. 1.5-3.5 per cent., Fe. 0.6 per cent.. Mg. 2-4 per cent., Zn. 4-6 per cent., Ni. $\geqslant$ 1 per cent.. Si. $\geqslant$ 0.6 per cent., Ti. $\geqslant$ 0.3 per cent.

After a solution heat-treatment at 460°C., followed by an ageing treatment at 130°C., the following mechanical properties are consistently obtained :—

0.1 per cent. proof stress 28-33 tons/in.^{2}, U.T.S. 33-38 tons/in.^{2}, elong. 10-18 per cent., Wohler fatigue range of $\pm$12.5 tons/in.^{2}.

(*e*) Mention must also be made of "Y " alloy, having the following nominal composition :—

Cu. 4 per cent., Ni. 2 per cent., Mg. 1.5 per cent., Si. $\geqslant$ 0.6 per cent., Fe. $\geqslant$ 0.6 per cent.

The alloy is heat-treated by quenching, in hot water, from 520°C., and either aged at room temperature or by precipitation treatment at 100-200°C. It develops remarkably good properties at elevated temperatures, and has the following minimum properties at room temperature :—

0.1 per cent. proof stress 14.0 tons/in.^{2}, U.T.S. 24 tons/in.^{2}, elong. 15 per cent.

It is used almost solely as forgings or parts machined from bar.

(2) Heat-Treatable Alloys not Containing Copper.

To this classification belong alloys of the type having the following nominal composition :—

Si. 1 per cent., Mg. 0.6 per cent., Mn. 0.75 per cent. (optional).

After quenching from 520°C., and ageing at room temperature, the following minimum mechanical properties are developed :—

0.1 per cent. proof stress 10 tons/in.^{2}, U.T.S. 17 tons/in.^{2}, elong. 20 per cent.

This alloy responds to precipitation heat-treatment, and when treated at 165°C., after quenching from 520°C., may have the following range of mechanical properties, according to time and temperature of precipitation heat-treatment :—

0.1 per cent. proof stress 15-19 tons/in.^{2}, U.T.S. 20-23 tons/in.^{2}, elong. 10/16 per cent.

This alloy is available in every wrought form. As it is not very strong, it is usually employed in secondary structures and is useful for open or pressed parts such as cowlings, fairings, etc.

A word may be said here about the corrosion resistance of the heat-treatable wrought alloys. In general, those alloys which are aged at room temperature have a fairly high resistance to corrosion, but those alloys which require to be aged at elevated temperature for development of optimum tensile properties are susceptible to intercrystalline corrosion. Of these alloys, those of the type not containing copper, are by far the most resistant. Adequate protection, however, renders these alloys quite serviceable in aircraft manufacture.

(3) Non-Heat-Treatable Alloys.

Chief amongst these alloys are the aluminium-magnesium series. These alloys have a high resistance to corrosion by marine atmospheres and waters, and, in addition, some of them may be produced to have strengths which are comparable with the heat-treatable wrought alloys. An alloy, the most important for structural purposes, having the following nominal composition:—

Mg. 7 per cent., Mn. 0.25 per cent.,

has the following minimum mechanical properties:—

0.1 per cent. proof stress 10 tons/in.^{2}, U.T.S. 20 tons/in.^{2}, elong. 20 per cent. (annealed).

0.1 per cent. proof stress 15 tons/in.^{2}, U.T.S. 25 tons/in.^{2}, elong 15 per cent. (cold-worked).

This alloy is available in all the forms in which duralumin may be obtained, including rivets. It work-hardens considerably and has to be designed for rather carefully to allow it to be used; it is employed very widely in Germany. An alloy consisting only of 5 per cent. Mg. in addition to Al. is particularly suitable for the manufacture of rivets. In the form of wire, it has a tensile strength of 16 tons per sq. inch, and has the advantage that, when used in the form of rivets, heading may be done at any time, and the difficulty occasioned by heading up immediately after quenching, as in the case of duralumin, is avoided.

Another alloy, containing 2½ per cent. Mg. and 0.25 per cent. Mn. has a high resistance to corrosion, is extremely workable, and, in the annealed condition, has a U.T.S. of 12.5 tons/in.^{2} with an elongation of 20 per cent. This alloy is particularly useful in sheet form, where much manipulation has to be done, and where stresses are not unduly high, and is also useful for soft tubes for petrol and lubrication systems.

An interesting development in the improvement of the resistance of these alloys to corrosion is that of the addition of chromium. Such an alloy, used for pressed and formed parts, contains 1.5-3 per cent. Mg. and 0.1-0.35 per cent. Cr. This alloy, which also develops a tensile strength of about 12 tons/in.^{2} with an elongation of 20 per cent., is claimed to have a very high resistance to corrosion.

Mention must also be made of the very important group of "clad" materials. They consist of a 5 per cent. coating of very pure aluminium on each side of sheets or strips of aluminium alloys of the "ordinary" or "improved" duralumin types. In this way a combination of lightness, strength and exceptional corrosion resistance is obtained. Not only is protection given where the coating is complete, but the underlying metal is electrolytically protected when exposed at sheared edges or at scratches and abrasions. The softness of the skin, however, is somewhat of a nuisance during construction or in service.

With regard to the corrosion of aluminium alloys in general, the anodic oxidation method has been so perfected that it gives almost complete protection, especially when supplemented by suitable paints or varnishes.

Cast Aluminium Alloys.

(1) Copper and Copper-Zinc Alloys.

The value of copper and zinc as hardeners for aluminium casting alloys has been recognised from the early days of the industry. Straight zinc alloys are very rarely used nowadays, however, mainly because they tend to crack in the mould owing to hot shortness. Considerable improvement was recorded by adding to such alloys a small quantity of copper, and of this type of alloy, that containing about 13½ per cent. of zinc, with 2½ per cent. of copper, is by far the most popular. Its mechanical properties are as follows:—

Sand cast:—0.1 per cent. proof stress 3½-4 tons/in.², U.T.S. 9-11 tons/in.², elong. 2-4 per cent.

Chill cast:—0.1 per cent. proof stress 3½-4 tons/in.², U.T.S. 11-14 tons/in.², elong. 3-8 per cent.

This alloy has certain disadvantages. It is still rather hot short and has very poor strength at high temperatures, its specific gravity is higher than that of many other alloys and it shows a tendency to spontaneous cracking during the first few months after casting.

For metal mould castings, a straight copper alloy is more suitable, and a common alloy for this purpose is one containing 6-8 per cent. of copper. The mechanical properties of this alloy are as follows:—

Sand cast:—0.1 per cent. proof stress 3½-4 tons/in.², U.T.S. 7½-9 tons/in.², elong. 1½-2½ per cent.

Chill cast:—0.1 per cent. proof stress 3½-4 tons/in.², U.T.S. 9/11½ tons/in.², elong 3-5 per cent.

The addition of still more copper increases the hardness of the material, but there is a reduction in ductility with no material addition to strength. An alloy, originally used for pistons—although not employed for that purpose to-day—still finds uses. It contains about 12 per cent. of copper, and its mechanical properties are as follows:—

Sand cast:—0.1 per cent. proof stress 4½-5 tons/in.², U.T.S. 7-8 tons/in.², elong. 0-1 per cent.

Chill cast:—0.1 per cent. proof stress 4½-5 tons/in.², U.T.S. 9/11 tons/in.², elong. 0-1.5 per cent.

(2) Silicon Alloys.

The alloys of aluminium and silicon are particularly interesting, and have a very considerable use nowadays. An alloy containing about 13 per cent. of silicon, when subjected to the process known as modification, which consists in treating the melt before casting with metallic sodium, or a suitable salt of sodium, undergoes a considerable improvement in its properties as a result of the refinement of the structure. The mechanical strength of these modified alloys is high, and this strength is accompanied by a large measure of elongation. Unfortunately, the elastic limit, in spite of the high strength, is no higher than that of the other common casting alloys, the metal is soft, and is not easily machined. The alloy, however, has a very high resistance to corrosion, and has found use for service on ships, and for parts of chemical plant. From the casting point of view, the alloy is particularly easy to handle. It is extremely fluid, and has a very low contraction of solidification, so that it may be cast into forms which have very thin sections. The mechanical properties of the alloy in the modified condition are as follows:—

Sand cast:—0.1 per cent. proof stress 3½-4 tons/in.², U.T.S. 10½-11 tons/in.², elong. 5-8 per cent.

Chill cast:—0.1 per cent. proof stress 4-4½ tons/in.², U.T.S. 13-14 tons/in.², elong. 8-15 per cent.

A more recent development of this alloy consists in the addition of a small quantity of magnesium, which makes the alloy heat-treatable; in different heat-treated conditions it is called Silumin Beta or Silumin Gamma (or Alpax Beta and Alpax Gamma). The first name is applied to castings that have been subjected to a precipitation treatment only (16-20 hours at 150°C. to 170°C.). "Gamma" is applied to material that has been solution-treated at 520°C. to 535°C., quenched in cold water and then given the precipitation treatment given to the "Beta" castings. In these conditions, the following properties are developed:—

Beta:—0.1 per cent. proof stress 4-5 tons/in.², U.T.S. 12-13 tons/in.², elong. 4-8 per cent.

Gamma:—0.1 per cent. proof stress 6-8 tons/in.², U.T.S. 15/16 tons/in.², elong. 2-6 per cent.

(3) Heat-Treatable Cast Alloys.

By far the best known of the heat-treatable cast alloys of aluminium is "Y" alloy, which contains 4 per cent. of copper, 2 per cent. of nickel, and 1½ per cent. of magnesium. In the cast condition, this alloy has not any remarkable properties, but after heat-treatment a considerable increase in strength is obtained. The heat-treatment consists of solution treatment at a temperature of 500-520°C. for about six hours, followed by quenching in boiling water. The alloy may be permitted to age at room temperature, or the ageing may be accelerated by treating for about two hours at 100°C. "Y" alloy is a difficult alloy to cast, but its popularity is due to its strength in the heat-treated condition, and at elevated temperatures. The mechanical properties of the alloy, when cast and heat-treated as described above, are as follows:—

Sand cast:—0.1 per cent. proof stress 13-14 tons/in.², U.T.S. 14-15 tons/in.², elong. 0-1 per cent.

Chill cast:—0.1 per cent. proof stress 14-15½ tons/in.², U.T.S. 18-20 tons/in.², elong. 2-4 per cent.

The straight copper-aluminium alloys may be heat-treated. For example, a 6 per cent. copper alloy, when heat-treated, will have a tensile strength equivalent to "Y" alloy with greater elongation, but a lower elastic limit. Below are given the mechanical properties of such an alloy, heat-treated at 500°C., for about twelve hours:—

Sand cast:—0.1 per cent. proof stress 7½-8½ tons/in.², U.T.S. 14-15½ tons/in.², elong. 2-3 per cent.

Chill cast:—0.1 per cent. proof stress 7-8 tons/in.², U.T.S. 19-21 tons/in.², elong. 8-13 per cent.

These alloys are not used to any extent.

A most important series of casting alloys of aluminium, known as the RR alloys, has been introduced for aircraft purposes during the last eight years. The comprehensive composition of the whole series is:—Cu. 0.5-5 per cent., Ni. 0.2-1.5 per cent., Mg. 0.1-5 per cent., Fe. 0.6-1.5 per cent., Ti. $\geqslant$ 0.5 per cent., and Si. 0.2-5 per cent. They are in very extensive use and probably yield the majority of aircraft castings. There are two main types, RR53 suitable for pistons and RR50 for general purposes; their percentage compositions are as follows:—

	Cu.	Ni.	Mg.	Fe.	Ti.	Si.
RR53	1.5/2.5	0.5/2	1.4/1.8	1.2/1.5	0.2/1.2	$\geqslant$2
RR50	0.9/2	1/1.75	0.05/3	0.8/1.4	0.02/0.2	$\geqslant$2.8

For RR53 a double heat-treatment is specified:—Solution heat-treatment of heating at 510-535°C. for 2-4 hours and quenching in water; precipitation heat-treatment of heating at 155-175°C. for 20 hours and quenching in water. For RR50 no solution heat-treatment is specified:—After cooling from the mould, the alloys are given a precipitation treatment by heating at 155-175°C. for 8-20

hours followed by quenching in water. The minimum properties obtained from these alloys are:—

	0.1 Proof Stress.	U.T.S.	Elong %	B.H.N.
RR53	19 tons/in²	20 tons/in²	1	106/140
RR50	8 tons/in²	13 tons/in²	4	59/80

The above discussion has centred round certain main groups of alloys mutually distinguishable by essential differences in chemical compositions. These in turn give rise to a number of commercial variations, incorporating very small additions of elements chiefly for grain refinement purposes. Some of the materials previously referred to include small additions of chromium or titanium; it may be noted that cerium, columbium and molybdenum are similarly used and yield a range of commercial alloys, principally heat-treatable castings, although forgings and extrusions of this type are also produced.

(*b*) Modern Magnesium Alloys.

In the very earliest production of magnesium alloys, entrapped flux, and the highly reactive nature of the metal, were responsible for many disappointments. Modern production has eliminated many of the problems in casting, although their quality still leaves much to be desired; however, magnesium alloy castings of high purity and a fair degree of soundness are now finding widening applications.

(1) Casting Alloys.

Large and highly complex sand castings can be made in magnesium alloys with no greater difficulty than attends the production of similar castings in aluminium alloys. Gravity die castings are being successfully produced, but the existing dies for aluminium alloys require some modification. This latter condition applies also to pressure die castings, numerous forms of which are now in production. The advantages claimed for the magnesium alloys are:—(1) 40 per cent. weight reduction compared with aluminium, (2) freedom from embrittlement in service, (3) absence of pinholing, (4) simplified design in the elimination of cored holes and pockets without appreciable increase in weight, and (5) achievement of stiffness with low weight. Numerous specifications for magnesium alloys cover a wide range of compositions and properties. The general composition of this group of casting alloys is covered by the following limits:—Al. 0.2-11 max., Zn. 0.2-3.5 max., Mn. 0.5-2.5 max. Two methods of treatment are available, a solution heat-treatment, usually consisting of heating at 420°C. for 24 hours (during this treatment, the metal is protected either by using an SO_2 atmosphere or employing a dichromate salt bath) or, alternatively, a precipitation hardening treatment of from 12 to 48 hours at 150-200°C.; some of the alloys are used in the "as cast" condition. Within this group, the derived properties vary widely with composition; it must suffice to quote two essentially different types. The first has a maximum composition of 8.5 per cent. Al., 3.5 per cent. Zn., and 0.5 per cent. Mn.; castings of this alloy are used either in the "as cast condition" or after solution heat treatment; the maximum composition of the second alloy is 0.2 per cent. Al., 0.2 per cent. Zn., 2.5 per cent. Mn.; it is used only in the cast condition. The mechanical properties of these alloys are:—

		0.1% Proof Stress.	U.T.S.	Elong. %
1	Sand Cast	4½/5½ tons/in²	9/11 tons/in²	3/5
	Sand Cast & S.H.T.	4½/5½ tons/in²	14/16 tons/in²	9/14
2	Sand Cast	1½ tons/in²	6/7 tons/in²	3/5

The first type is the typical product of this general group of magnesium alloys; the second is used for lightly stressed parts and is easily welded.

Magnesium alloy castings offer many attractions in applications where their low specific gravity (1.81-1.83) is advantageous; for aircraft purposes, they are chiefly used for crankcases and covers, landing wheels and various engine parts and body fittings.

(2) Wrought Alloys.

These alloys lend themselves without serious difficulty to extrusion, hot rolling and forging and are thus available in all the usual wrought forms and most of the sizes in which the wrought aluminium alloys are obtainable; magnesium alloys, however, *cannot* be cold-worked.

The Mg.-Mn. group yields an alloy notable for weldability; as it also possesses superior workability and corrosion resistance, it provides the sheet alloy largely used for the fabrication of fuel and oil tanks, containers, panelling, etc. It has a maximum content of 2.5 per cent. Mn. with small allowable impurities of Al. (0.2 per cent.) and Zn. (0.2 per cent.). It exhibits a 0.1 per cent. proof stress of 6-8 tons/in.^{2}, an U.T.S. of 12-15 tons/in.^{2}, and an elongation of 7-10 per cent.

The Mg.-Al. alloys are used for structural purposes and stressed parts and supplied mainly in the form of extrusions, also sheet and forgings. The general composition of the group is covered by the maximum composition limits of 7.5-11 per cent. Al., 1.5-2 per cent. Zn., and 1 per cent. Mn. As typical examples we may select three alloys which find extensive use for (i) sheet, (ii) bars and extrusions, (iii) crankcase and airscrew forgings; calling these A, B and C, respectively, their compositions and tensile properties are as follows:—

	Al. (max.)	Zn. (max.)	Mn. (max.)	0.1% Proof Stress t./in^2	U.T.S. t./in^2	Elong. %
A	9	1.5	1.0	7	16	10
B	11	1.5	1.0	9/11	14/17	5/10
C	11	2.0	1.0	10/12	17	5

As magnesium alloys present certain peculiar difficulties in certain directions, a brief note may be added on these aspects. With regard to bending, shaping, deep-drawing and similar operations, the difficulties of cold-working must be accepted and advantage taken of the ease with which the alloys may be worked at temperatures around 300°C.; further, for all deformation processes, especially deep-drawing, the slower the speed, the better the result. Several of the wrought alloys and castings may be successfully welded by the oxy-acetylene process using appropriate welding rods and fluxes; the welding flux, however, is highly corrosive and must be most carefully removed from the welds, by washing, brushing and chromating. With regard to the machining aspect, the use of a high cutting speed is to be advocated, using very sharp tools and fairly heavy cuts. Danger of fire is small when the chips are reasonably heavy, but when using an insufficiently coarse cut and a blunt tool, it is possible locally to heat to above the melting point and so produce a " swarf " fire. For riveted construction, rivets of an aluminium alloy containing 5 per cent. Mg. are recommended by the makers. The intrinsic low resistance to corrosion of Mg. alloys is still a great disadvantage and greatly restricts their applications to exposed parts. Chromating solutions are used as a basis for paint and enamel finishes; the two types most commonly employed are the dichromate short time immersion, giving a golden yellow film, but producing a wastage of the alloy that cannot be permitted in certain cases, also, the " R.A.E. baths " (30 minutes and six hours) which, producing a black finish on Mg. Al. alloys and a brown finish on Mg. Mn. alloys, only result in negligible wastage. But the broad position is that although the coatings described are good enough for ordinary purposes, they are markedly inferior to the anodic oxidation as applied to aluminium alloys; for sea water corrosion, there has not yet been developed *any* reliable corrosion-resisting treatment for alloys of magnesium, so that the existing coatings can only be described as palliatives, not good enough for some of the exacting conditions of modern aircraft.

In the above survey, attention has been confined to commercially available alloys of magnesium. But considerable research has been made at the National Physical Laboratory in recent years into alloys containing cerium, nickel, cobalt, manganese, silver and calcium and, while the practical applications of these alloys are still largely in the experimental stage, there is reason to hope that useful

practical applications to aircraft construction will emerge. An account of this work will be found in the paper[20] by Dr. Desch.

Metals constitute the most important materials of aircraft construction. The principal types available have been surveyed in the present section so far without any indication of the relative extent to which they are employed in typical aircraft. In the engine, as shown by Table II, steels of a great variety of types constitute between 42 per cent. and 48 per cent. of the total weight; the light alloys which amount roughly to 53 per cent.—47 per cent. of the engine weight, appear in the form of castings or forgings. The most important castings are of high quality annealed or heat-treated alloys of aluminium *or* magnesium; both are employed. The important stressed forgings are practically all of heat-treated aluminium alloys. Turning to the airframe, modern construction is almost entirely of light alloys. The forms most used for main members are either extruded sections or large tubes, some of which are tapered in the gauge. The use of extruded sections is extended throughout the structure, where the dimensions are suitable, and the framework of the modern aircraft seems to consist of extruded sections and tubes. A most astonishing variety of shapes and sizes is available, typical examples of which are illustrated in Fig. 16, which also indicates some of their applications. In general, the tubes are in alloys of the ordinary duralumin type, the extruded sections being of the same alloys or in alloys of the " improved " duralumin type. With regard to coverings, there is a general tendency towards the use of the " clad " aluminium alloys. For internal structures, there is a fairly general application of aluminium alloys of the ordinary duralumin type. Magnesium alloy sheets and extrusions are used in parts which are entirely secondary for weight-saving purposes. In other items of construction, the tendency is to get away from built-up pieces and to replace these with forgings or large extruded sections and, in some cases, with castings, where it is impossible to make a forging; but the use of castings is not extensive and forgings are used wherever possible. Taking aircraft in general, without reference to any particular machine, the following estimate of distribution is probably not widely out. As far as sheet materials are concerned, about 50 per cent. are made of plain duralumin, about 40 per cent. of one of the " clad " materials, the remainder in one of the stronger types. About 60-70 per cent. of extrusions and parts machined from bars will be of plain duralumin, the remainder in one of the " improved " types such as RR56. Of forgings used in the structure, about 60 per cent. are of plain duralumin, the remainder of higher strength alloys. About 80 per cent. of the tubes will be of plain duralumin, the remainder, again, of the higher tensile alloys. With regard to airscrews, the position has been summarised in the section devoted to that component.

3. Some Special Alloys.

Although, in general, aircraft requirements demand metals possessing high specific tenacity coupled with other desirable properties, the balancing of such components as crankshafts and variable pitch propellers, creates a need for a material of very high density to effect the maximum economy of bulk. The specific gravities of the ordinary engineering metals and alloys—steel, brass, bronze, copper, nickel—fall within the approximate limits of 7 and 9; it is true that lead has a value of 11.4, but its use is greatly restricted owing to low tensile strength and tendency to creep. It is among the rarer metals that the high densities are encountered, the specific gravities of tantalum, gold, tungsten, platinum, iridium and osmium being 16.6, 19.3, 19.3, 21.5, 22.4 and 22.5, respectively, but considerations of cost or manufacturing difficulties have hitherto excluded any of them from such mundane uses as balance weights. Recently, a most interesting

[20] " Magnesium Alloys." C. H. Desch, Jour. Roy. Aero. Soc., No. 317, Vol. XLI, May, 1937.

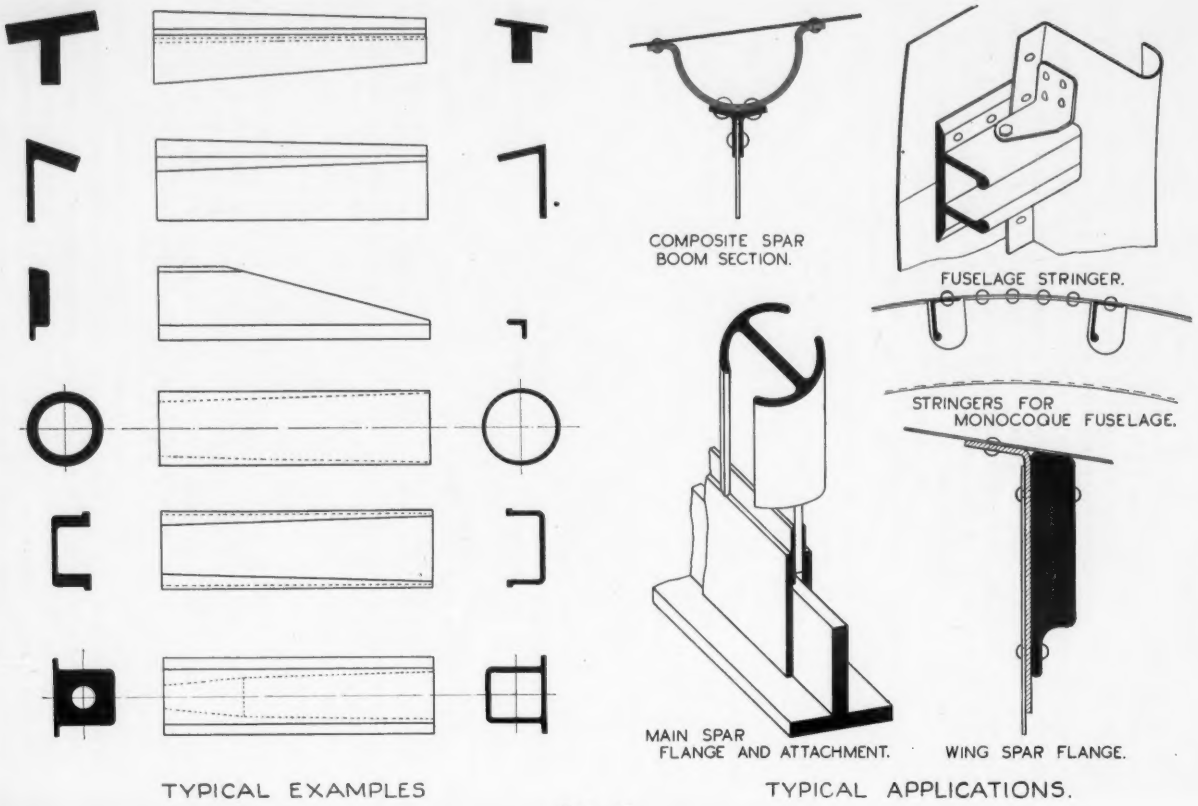
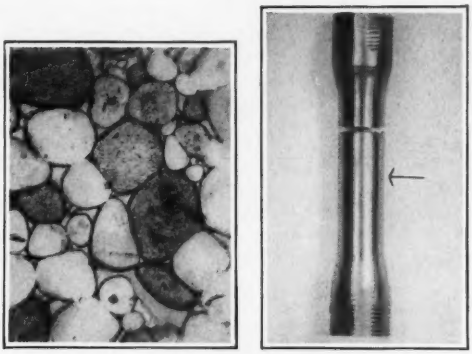


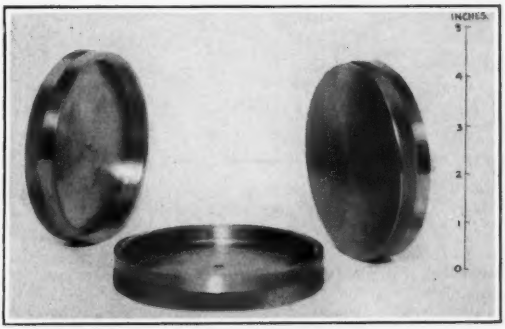
FIG. 16.

Extruded sections of aluminium alloys.

new alloy,[21] termed " Heavy Alloy," has been made available by the electrical industry who have utilised the extended experience of sintered alloys, gained in the manufacture of incandescent lamp filaments, to produce a material which is already in use for the aircraft purpose mentioned. " Heavy Alloy " contains 90 per cent. of tungsten, 4 per cent. of copper and 6 per cent. of nickel. Pure tungsten has a tensile strength of over 100 tons/inch² and the highest elastic



A. Microstructure × 500. *B. Welded test piece broken at* 40 *tons/in.*². *The spherical grains are tungsten. The arrow indicates the weld.*



C. Group of balance weights. Machined, screwed and knurled.

FIG. 17.

Heavy alloy containing 90% *W.,* 4% *Cu.,* 6% *Ni.*

modulus of any metal but its high melting point—3,400°C.—has hitherto prevented its production in massive form. The problem has been solved, in the research laboratories of the General Electric Company, by mixing tungsten powder with a small proportion of metals of lower melting point, so that a liquid phase is formed on heating to a moderate temperature; this results in complete alloying of the constituents, shrinkage takes place and alloys entirely free from porosity and

[21] " Sintered Alloys." Price, G. H. S., Smithells, C. J., and Williams, S. V., J. Inst. Metals, 1938, 62 (Advance Copy).

having the theoretical density are obtained. Between 5 per cent. and 10 per cent. of a mixture of nickel and copper powders is added to the tungsten powder, which is then pressed to the required shape in a steel die and heated in hydrogen at about 1,450°C. A complete change in structure takes place during this heat-treatment, the fine tungsten particles being replaced by large spherical grains of tungsten embedded in a tough matrix of copper-nickel-tungsten solid solution, giving the microstructure shown in Fig. 17; the physical properties of the alloy are attributed to this combination of the hardness of the tungsten grains and the strength and toughness of the copper-nickel matrix. The physical properties of " Heavy Alloy " are summarised in the table.

TABLE IV.

PHYSICAL PROPERTIES OF " HEAVY ALLOY ": 90 PER CENT. W., 4 PER CENT. CU., 6 PER CENT. NI.

Tensile Strength, tons/in^2:	40
Yield Point, tons/in^2:	37
Elongation, % on 1in.:	4
Young's Modulus (E), lb./in^2:	32×10^6
Brinell Hardness:	250/290
Specific Gravity:	16.3/17
Coefficient of Expansion:	5.6×10^{-6}
Thermal Conductivity, C.G.S. units:	0.25
Specific Resistance, ohm./cm.^{3}:	1.16×10^{-5}

The alloy is stated to be completely resistant to atmospheric corrosion or salt water, can, if desired, be plated with nickel, cadmium or chromium, and is readily machined with ordinary tools. It can be brazed or silver-soldered to other metals (soft soldering is not recommended). A special method of welding in hydrogen has been developed for joining together components made of heavy alloy which gives a homogeneous weld; a fractured welded sample is shown in Fig. 17, which broke at a stress of 40 tons/inch^2, in a region remote from the weld. A group of balance weights, as used in a variable pitch propeller, is also shown in the figure. " Heavy Alloy " has been described in some detail not only because of its special interest as a recent development having aeronautical application, but also to draw attention to the marked possibilities of the science of powder-metallurgy. A valuable treatise[22] has been published on the subject, containing an account of the principles and present industrial uses of the sintered alloys. It is clear that the possible applications of powder-metallurgy have not as yet been fully appreciated and that the method in general may take a prominent place in the working-up of metals in the future. The time may come when large ingots, prepared in this way, may be used in commercial production, giving standards of purity, uniformity and freedom from segregation which, although always the ideals of the aircraft industry, have not hitherto been attainable.

The heavy non-ferrous metals of the usual types, brasses, bronzes, etc., find only a limited, though important use, in aircraft construction; their properties, however, are well-known and need no mention in the present brief review. Some special derivatives of the well-known Monel metal (essentially a high nickel-copper alloy, containing 65-70 per cent. Ni., 26-30 per cent. Cu., with additions of Fe., Mn., Si. and C.) may be mentioned. The addition of about 4 per cent. of aluminium induces a response to thermal hardening of the precipitation type; a combination of cold-work and subsequent thermal hardening enables a tensile strength of up to 70 tons/inch^2 to be obtained. Moreover, this material, known as " K-Monel," is practically non-magnetic, rendering it suitable for stressed parts which are in proximity to the compass; it is understood that, in certain foreign planes for marine purposes, it is used for straining wires and anchorages. A further development is the alloy " Inconel " containing about 80 per cent. Ni.,

[22] " Powder Metallurgy." W. D. Jones, 1937, Edward Arnold & Co., London.

13 per cent. Cr., 7 per cent. Fe., which can be hardened by work, but not by heat-treatment; work-hardening raises the tensile strengths from 35-50 tons/inch^2 to an upper limit of about 85 tons/inch^2. Its resistance to heat-oxidation at very high temperatures finds application in silencers and exhaust manifolds. The valuable use of an 80-20 Ni-Cr. alloy for covering the heads of engine valves has already been referred to, also the possibility, now in course of development, of making the complete valve of this material. With regard to the lead-bronzes, which find such an important use as the lining for engine bearings, it will be sufficient to give references to publications describing tests,[23] an extensive investigation into the effect of various compositions,[24] methods of manufacture[25] and bearings[26] for high duty work.

B. Wood.

Any review of the materials of aircraft construction of 1938 would be incomplete if mention of wood was omitted, because the recent developments in that field open up many possibilities. Natural woods, of course, remain essentially the same as ever but the collaboration of the chemist and the process engineer has produced derivatives from natural woods which form something akin to a range of new materials. These improved woods are similar to synthetic plastics in that they were not primarily developed for the aircraft industry but for electrical and other purposes; they have now attracted the interest of the aircraft designer, have been already employed to some extent, are being experimented with in a variety of ways and may find extensive use in the future. If reference is made to that most valuable book,[27] on aircraft materials, by Jenkin, published in 1920, it will be found that he devotes almost exactly 25 per cent. of that volume to timber; the data therein given, still form one of the most valuable and accurate compilations on the subject. In his opening paragraph, however, he predicts the probable disappearance of wood from the aircraft field in favour of metal and, until quite recently, the accuracy of that prediction would not have been doubted; it now appears highly probable that, at all events, in certain types of aircraft, the new improved woods may find important uses. The disadvantages of natural wood include the variation of moisture content with changes in humidity involving impermanence of dimensions and form, coupled with the low compression strength in the direction of the grain, although, in the same direction, the tensile strength is such as to confer on wood an exceptionally high specific strength. At the period reviewed by Jenkin, the jointing materials available were hide glue, used hot, and casein cement, used cold, but their performance was such that Jenkin stressed the urgent need for a much better adhesive in order to give greater opportunities for the development of plywood. He was also fully alive to the possibilities of obtaining improved woods by suitable chemical treatment but the method tried at that time—impregnation with sodium silicate—proved most unsatisfactory.

The credit for the present position must be given, in the first place, to the chemist, for having developed synthetic resinous glues of excellent adhesive and moisture-resisting qualities. Two typical resins, approved for aircraft construction in this country, are urea formaldehyde products which are caused to condense or polymerise to a hard insoluble synthetic resin by the addition of catalysts; the process of solidification takes place sufficiently slowly to allow proper time for gluing and clamping of the parts to be joined. These glues are stated to be free from the disadvantages associated with casein glue, *i.e.*, susceptibility to attack

[23] T. E. Stanton. Aero. Res. Cttee., Repts. & Mem. Series No. 1424, Dec., 1930.
[24] H. K. Herschman & J. L. Basil. Bur. Stds., Jour. Res., Vol. 10, 1933, pp. 591/608.
[25] K. Nischk. Metal Industry, April 3rd, 1936, pp. 415 to 422.
[26] H. N. Bassett. The Metal Industry, Vol. LII, No. 1, Jan. 7, 1938, pp. 25 to 32.
[27] Report on the Materials of Construction used in Aircraft and Aircraft Engines. C. F. Jenkin, 1920, H.M.S.O., London.

by mould, fungus, and water (to present the picture fairly, however, it must be remarked that casein glue is still used as an adhesive in glued and clamped joints where the applied pressure is indeterminate). The manufacture of ordinary plywood has been almost revolutionised, as a matter of practical convenience, by the advent of a phenol formaldehyde resin which is sometimes applied wet but much more frequently in the form of sheets of paper previously soaked in the resin and then dried. The impregnated paper, usually about 0.1 mm. in thickness, is interleaved with thin wood veneers, the assembly then being glued together, at 140°C., in a plywood press; the process is clean and gives a material of outstanding characteristics. With such glues, the joints in plywood need no longer be sources of weakness, the main objection to laminated wood disappears and the fullest advantage can be taken of combinations of veneers of different timbers and varied direction of grain to produce sheet of much improved strength.

Quite a number of different processes have been developed to produce these improved woods but most of these fall into one of two types. In the first type, synthetic resinous material is used primarily as a binding agent for thin veneers, being applied as a surface film, without previous *impregnation* of the wood subsequently subjected to pressure and heat. The resin content is much less than in the second method to be described and, on this account, better specific strength in tension and shear together with improved adhesion are obtained. In the second method, the synthetic resin is used as a filling material for the wood; much thicker plies being soaked[28] for some time in resinous material before being pressed. As both the resin content and amount of compression are controllable factors, within certain limits, the specific gravity of the final material can be made to vary from that of the natural wood, 0.75 for example, to an upper limit for which the value of 1.4 is rarely exceeded in practice. Veneers of different woods may be employed in combination, while the grain direction in these various veneers may be arranged as required. Such processes as described normally give a block having a density and physical properties constant along its length. By suitable transitions in the nature of the veneers, in their number and in the degree of compression employed, blocks can be produced in which the strength and/or density vary continuously along the length of the block or, alternatively, change through a transition zone, from one type to another; the former type has applications, for example, for longerons or spar flanges, the latter in airscrew blocks. Then in some cases, one or more layers of fabric or similar material may be built up in the section and there are many other possible variations. Some of the arrangements and processes described are covered by patents; with this aspect, we are not immediately concerned but rather with an attempt to give a general descriptive account of the methods employed in making these improved woods. For detailed particulars, reference may be made to the published literature.[29]

With regard to the physical properties of these woods, test data relating to practically every type have very kindly been made available to the writer by users and makers but, owing to the employment of different test methods and lack of uniformity in the test programme, it is impossible to present these data in a sufficiently comparable form. Some general idea of the properties obtained from some commercial products may, however, be gained from data selected from the report of tests[30] made at the Royal Aircraft Establishment, to which reference is permitted; these data relate to 7 samples of laminated birch and 1 of laminated beech received during 1937, of which the general particulars are given in Table V; solid birch is included for comparison purposes.

---

[28] In some processes the wood is vacuum—impregnated with the synthetic resin.

[29] See, for example: (1) "Resin-Impregnated Wood." Anon, Plastics, Vol. I, 5, Oct., 1937; (2) "The Case for Wood." B. Jablonsky, "Flight," Dec. 16, 1937; (3) Improved Laminated Wood in Torsion. E. Reissner, "Flight," Jan. 27, 1938.

[30] "Laminated, Compressed and Impregnated Woods." W. D. Douglas, Air Ministry Report, 1938. (Unpublished.)

TABLE V.

DESCRIPTION OF SAMPLES OF NATURAL AND LAMINATED WOOD.

Description.	Density lb./cu.ft.	Specific Gravity.	No. of Veneers per inch of thickness.
Solid Birch	44	0.71	1
Laminated Birch	45.6	0.73	13*
,, ,, ...	54.3	0.87	50
,, ,, ...	56.4	0.90	49†
,, ,, ...	62.2	1.00	20*
,, ,, ...	69	1.10	34
,, ,, ...	86	1.38	81
Laminated Beech	86.9	1.39	12

* Veneers treated with resin in liquid form: all others with interleaved dry resin films.
† Every 8th veneer with grain transverse: all others longitudinal.

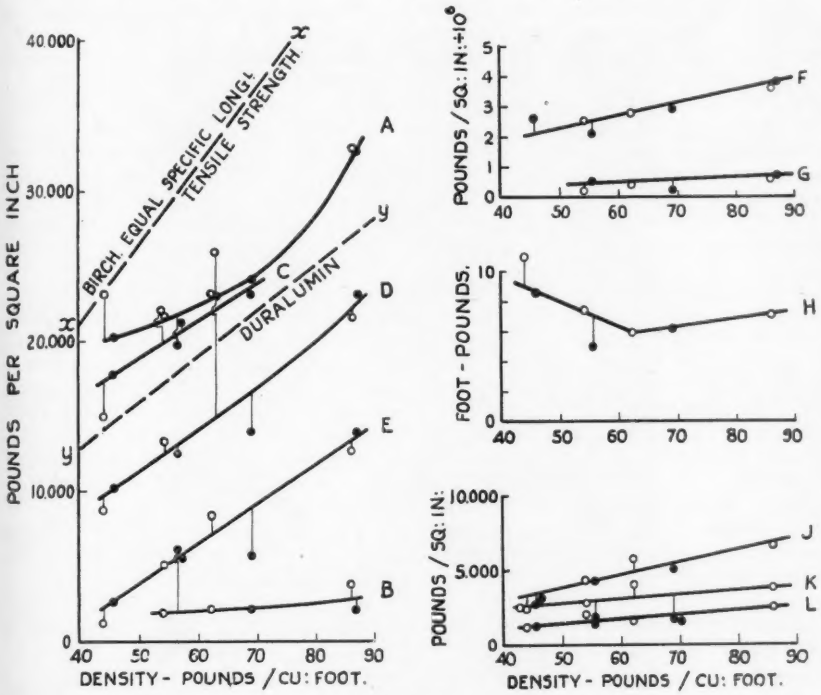


FIG. 18.

Tests on laminated compressed and impregnated wood.
Six of birch, one of beech, also solid birch.

A. Ultimate tensile: Longitudinal.
B. Ultimate tensile: Transverse.
C. Modulus of rupture in bending.
D. Compressive strength: Longitudinal.
E. Compressive strength: Transverse.
F. Young's modulus (E): Longitudinal.
G. Young's modulus (E): Transverse.
H. Notched bar impact.
J. Shear strength: Longitudinal, parallel to laminations.
K. Shear strength: Longitudinal, transverse to laminations.
L. Shear strength: Transverse, parallel to laminations.

These data are presented graphically in the curves of Fig. 18, plotted on a base of varying density. In such a diagram, straight lines radiating from the true origin represent lines of constant specific strength, *i.e.*, strength divided by density. Such a line, marked *xx*, has been drawn through the experimental value of the tensile strength (longitudinal direction) of birchwood, and is useful in comparing the corresponding experimental values for the laminated woods of curve (*a*) on the diagram; as a matter of interest, the similar line, *yy*, which refers to a duralumin having a tensile strength of 25 tons/inch^2, has been added to the diagram.

Fig. 18 indicates a general relationship between density and mechanical properties and this fact suggests the potential uses such materials may have for, by skilful choice of the nature and arrangement of the veneers also of the degree of impregnation and amount of compression employed, the properties at any position may be adjusted best to suit the amount and nature of the imposed stress system. These fabricated and impregnated woods can be joined and scarfed by adhesives and can be worked by woodworking processes. It may be mentioned that an impregnated and compressed hickory, having a density of 59.7lb./cu. ft., has given the following impressive test figures:—Tensile, compression and shear strengths of 36,500, 23,000 and 4,600lb./in.^{2} respectively, and value of Young's Modulus (E. at 5,000lb./in.^{2}) of 6.9×10^6lb./in.^{2}. With regard to unimpregnated but fully compressed material, the following figures relate to birch board having a density of 86lb./cu ft.; the tests were made on 12 such boards taken from current production material:—tensile strength 42,000-54,700lb./in.^{2}; compression strength 24,700-27,900lb./in.^{2}; shear strength 6,450-8,300lb./in.^{2}; Young's Modulus (E) $4.1\text{-}4.6 \times 10^6$lb./in.^{2}. For certain purposes, development is proceeding along the lines of a search for a better balance of selected physical properties which have to be obtained at the expense of, say, maximum tensile strength; this point is mentioned to show that a high tensile strength is not, in general, the most important characteristic. The *bearing* strength of wood is very important at places of attachment by bolts, etc., where failures occur by splitting along the grain; for loading of this type, laminated and compressed material is a great improvement on ordinary wood, while the addition of fabric inserts confer still greater resistance. Tests of this kind, made on spruce, showed that the laminated material was 2.4 and 4.4 times (depending on the orientation of the laminations) stronger than ordinary wood while the addition of fabric inserts raised the value to 6.4 times. In consequence, composite beams and structural components are being made where the compressed wood is *locally* reinforced to stand these shearing forces, another indication of the possibilities of these new materials.

It is an interesting point that laminated and impregnated woods exhibit fatigue characteristics generally similar to metals and ordinary woods. Wohler tests made on a material having a tensile strength of 30,000lb./in.^{2} and density of 70lb./cu. ft. developed a Wohler endurance limit of $\pm 8{,}300$lb./in.^{2} at 5×10^7 reversals.

The present principal applications of compressed woods to stressed parts of aircraft appear to be confined to wooden stress-skin fuselage, spars having physical properties varying along their length, also airscrew blocks. As far as what may be termed the " raw materials " are concerned, these do not lend themselves easily for illustration purposes but Fig. 19 may be of interest. It shows a stage in the manufacture of one type of block for airscrews in which a compressed and impregnated hard-wood root of beech or birch is scarfed, after process treatment, to a lighter blade material, spruce, with a suitable transition zone. The material of such a root has its tensile and shear strengths of about $2\frac{1}{2}$ times and $4\frac{1}{2}$ times, respectively, of those of the uncompressed wood. An illustration of another method—where a block containing, say, 60 veneers at one end and half that number at the other is compressed to a uniform thickness—has been published elsewhere.[31]

[31] " Flight," Dec. 16, 1937.

C. Rubber.

Any consideration, however brief, of rubber must be attempted under the two classifications of natural and synthetic rubbers; this will be followed by a note on the very interesting subject of rubber bonded to metal and a mention of expanded rubber.

1. Natural Rubber.

The general developments in rubber that have taken place in recent years are due mainly to improvements in compounding together with constant improvements in manufacture and technical control. The discovery of the reinforcing properties of gas (carbon) black, the use of organic accelerators of vulcanisation, of anti-

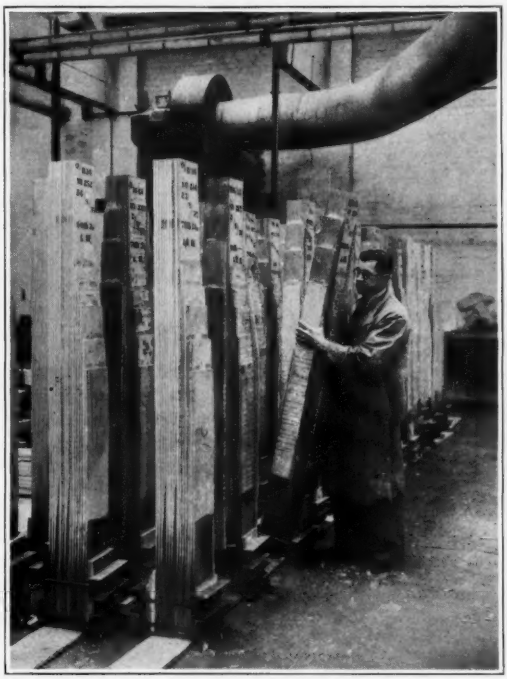


Fig. 19.

Stage in the manufacture of one type of airscrew block made of laminated and compressed wood.

oxidants of age and heat resisting ingredients have been mainly responsible for a steady improvement in quality particularly with regard to tensile strength and wear-resistance; nevertheless, so far, no anti-oxidant has been discovered which will protect entirely rubber against sunlight for any considerable length of time. Gas-black, prepared by the incomplete combustion of natural gases, is in a much finer state of division than lamp-black derived from animal sources. To its fine particle size, the former owes its reinforcing properties; for example, the proportion used in tread stocks for aeroplane and other tyres has progressively

increased, in the last 25 years, until it now forms as much as 50 per cent. of the rubber weight with greatly improved toughness and resistance to tearing and cutting.

Perhaps the outstanding development in natural rubber has been the production of " conducting " rubber, which is a most interesting, and perhaps curious, property to develop. But this type of rubber has very special and most valuable uses, of which the conducting aircraft tyre is the most relevant in the present connection. For it is essential that an aeroplane shall be electrically " earthed " immediately it touches the ground, otherwise static electrical charges, accumulated by air friction or during a thunderstorm, are discharged as a spark, with possible danger to personnel or of fire risk. The advent of conducting tyres has dispensed with the need for trailing wires or chains which are always liable to be lost or damaged. It is known that rubber can be made to conduct electricity by adding various ingredients of a conductive nature, but a high proportion of such material is required, and the resulting rubber is hard and cracks easily, while its conductivity is often not permanent. A method by which rubber can be made electrically conducting has been so perfected that no sacrifice is made of the other typical properties of rubber. Normal rubber is known as an insulator and the following comparisons may be of interest:—

	Approximate Specific Resistance ohms.
Copper	1×10^{-6}
Standard Tyre Tread Rubber	1×10^{9}
Pure Rubber	1×10^{16}

Actual tests made of the resistance of aeroplane wheels, measured between the hub and a wetted metal plate placed under the tyre to ensure good contact, gave the following results.

	Resistance: ohms.
Conducting Tyre	5 to 10×10^{3}
Standard Tyre	2×10^{10}

In the aeroplane conducting tyre, mainly used for tail-wheels, tyre, hub and bearing are made part of a simple conducting system, good contact between the tyre beads and hub being ensured by spraying the inside of the rim with metallic aluminium. Automatic earthing of the plane is thus obtained; it has been found that the time required to earth the static charge on one of the largest aeroplanes is about one ten-thousandth part of one second only. With an ordinary tyre, a period of at least 10 to 20 minutes would be necessary; a discharge time of over two hours has been observed under laboratory conditions.

2. Synthetic Rubbers.

Rubber technology is following on the scientific lines of the synthetic dye industry and the use of natural rubber will not die out; nevertheless, synthetic rubber-like materials are being produced which have unique properties, absent from the natural material, which fit them for a wide variety of novel purposes. It is due to their better resistance to sunlight, heat and oil that the synthetic rubbers find application in the aeronautical field. There are two types of synthetic rubber closely related chemically to natural rubber since they contain a butadiene " back-bone:" Neoprene which is made by the polymerisation of chlorbutadiene, and the Buna N which is an inter-polymer of butadiene and acrylic nitrile. In addition, there is the rubber-like plastic Thiokol which is made by condensing chlorinated ethylenes with sodium polysulphide and other similar products. Each of these products, in addition to being more resistant than natural rubber to oils, grease, heat, sunlight and ozone, has other valuable characteristics. Neoprene, for example, is unique in its flame-resisting properties and ease of bonding to metals: Bunas have unique resistance to low temperatures, while

Thiokol is the only product of the three with marked resistance to aromatic solvents.

Thus we find synthetic rubbers used in fuel hose and sealing strips for tanks because of their resistance to petrol; in lubricating oil hose, pressure grease systems, retractable carriage washers, brake drum bellows, engine mountings, gaskets and similar parts which are liable to come into contact with oil; in ignition cables, radiator hose, etc., because of their heat resistance; as a protective covering for metal seaplane floats, nuts and bolts and propellers, because of their resistance to corrosion and ability to be bonded to metals; in the production of expanded rubber for seating and flooring because of flame-resistance. Although not entirely relevant to the scope of the present lecture, it may be mentioned that the far greater impermeability to hydrogen over natural rubber has led to the use of synthetic rubber in balloon fabrics.

In concluding this brief survey, it may be mentioned that these synthetic rubbers[32] are really new raw materials each with its own characteristic properties and with potential uses to which natural rubber could never be put. They should not be regarded as mere substitutes for natural rubber but rather as extensions of the " rubber range."

3. Bonded Rubber and Metal.

The problem of bonding rubber to metal has been solved, during the last few years, on a practical and commercial basis; the development is of importance as, previously, rubber could only be used for energy absorption and filtering purposes by methods in which the material was subjected to compression only under conditions of lateral constraint. The advent of bonded rubber and metal now permits rubber to be used at will under tension, compression or shearing actions with complete freedom to distort without volume reduction. It is well known that the hardness of rubber, natural or synthetic, is a property which can be predetermined by controlled mixing during manufacture; not only is this property valuable in itself, but, because it is associated directly with the stiffness and, therefore, the natural frequency of the material, bonded rubber offers great opportunities for the scientific design of such components as engine mountings, couplings, etc., having resonant frequencies selected to suit the operative conditions. Such components are already in use to a limited extent in aircraft and appear to have extended possibilities in the future, as the high damping capacity of rubber is such an invaluable property. At present, natural rubber is almost entirely used as it is found adequate for the purpose and is very much cheaper; synthetic rubber may, however, come to be used in special cases where greater resistance to ageing, heat, oils, etc., may be required. Although rubber could, at first, only be bonded satisfactorily to steel and cast iron, complete success has now been obtained with aluminium and magnesium alloys, bakelite and glass. When bonding rubber to steel, for example, the metal is first plated, the rubber then being bonded on by heat and pressure, but in the case of certain synthetic rubbers such as neoprene a simple painting of the metal surface[33] with a solution of chlorinated rubber can replace the more expensive plating process.

Fig. 20 has been prepared to bring out the following essential features of rubber bonded to metal:—(1) the very considerable distortion to which rubber may be subjected under tangential stress, (2) that fracture occurs through the rubber and *not* at the bonding, and (3) that by control of mixing, rubbers can be obtained having different values of hardness and stiffness. The graph relates to 3 values of Shore hardness (30, 40 and 50), the full range now available being from 30 to 90.

[32] For a concise treatment of this subject the reader is referred to Dr. Naunton's book on " Synthetic Rubber," 1937. MacMillan & Co., London.

[33] " Bonding," Habgood, B. J. Trans. Inst. of Rubber Technology, 1937, XIII, 136.

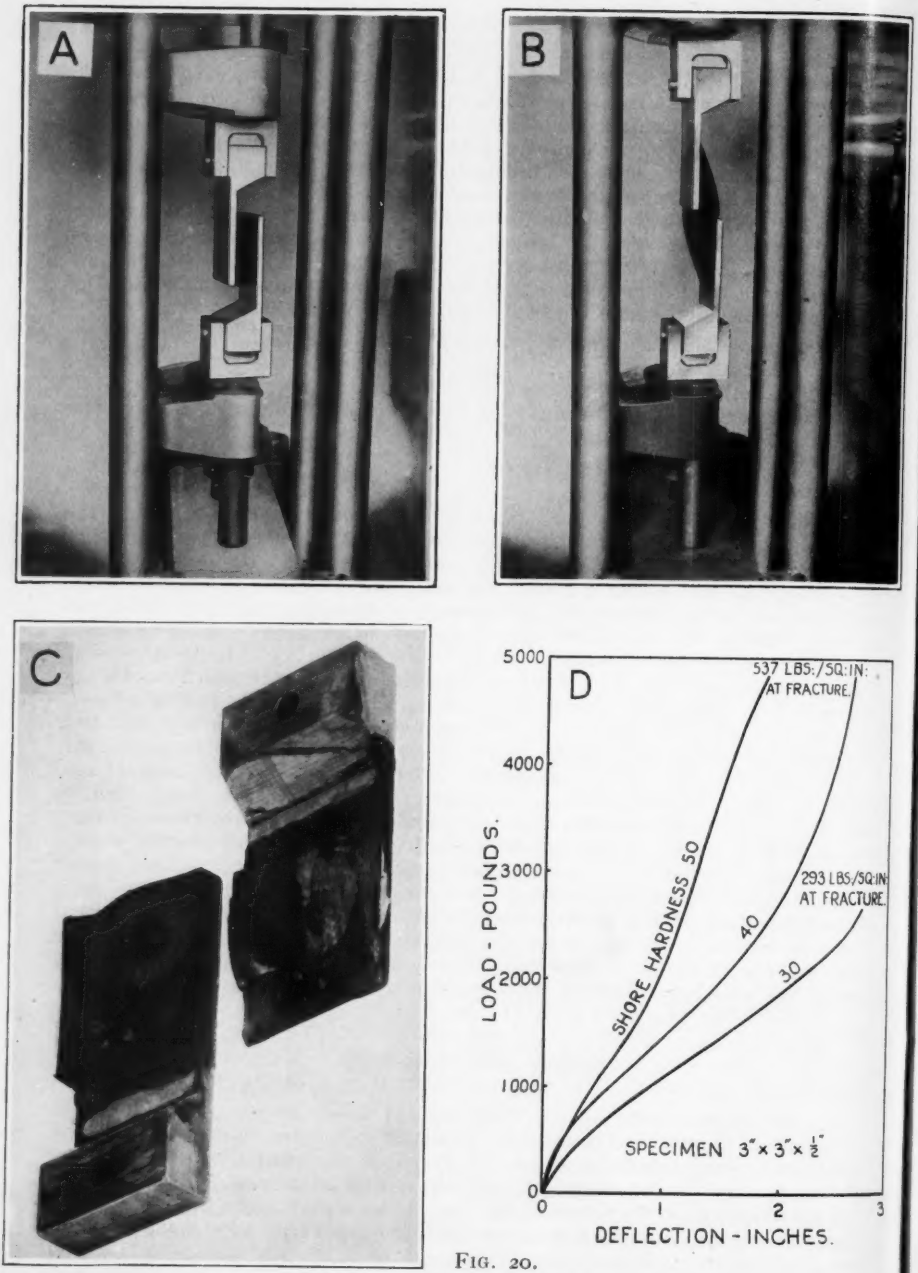


FIG. 20.

Tests on rubber bonded to metal.

A. Specimen unstressed.
B. Specimen under load.
C. Fractured specimen.
D. Shear tests on samples having hardness values of 30, 40 and 50.

4. Expanded Rubber.

This is a rubber compound expanded by an inert gas into a form which, viewed under the microscope, exhibits a structure of closed cells bounded by rubber compound membranes. The density can be varied at will from 3lb. to 7lb. per cu. ft., the material as normally produced having a density of less than half that of cork. Owing to the true cellular structure, this interesting material has a low moisture absorption; a sample soaked in water for 235 hours absorbed only 0.6 per cent. by weight. The material is easily worked or moulded to any required shape. It has already found several minor uses in aircraft construction, but experiments are also being made on its possibilities in wooden skin-stressed construction as a separator between plywood to which it may be bonded using a special synthetic resin.

D. Plastics.

In discussing the subject of Plastics in relation to aircraft purposes a considerable degree of caution must be exercised. For example, it is often inferred that there have recently been made great advances in their development but this is not a true picture of the position; actually, the principal steps taken in this direction in the aircraft industry arise from attempts made by that industry to make use of a group of materials already in existence. Such attempts are most interesting and promising but the possibilities can easily be over-stated and thus actual harm can be done to promising research; these remarks apply, of course, to the use of plastics for stressed construction, as plastics already find many useful applications in other directions in aircraft. That some of the aircraft of to-morrow may be of moulded construction in plastic material is an aim towards which much skill and enterprise is being directed, but it is by no means a certainty unless many serious difficulties are overcome. But, in this survey, mention of plastic materials must certainly find a place and, in the present section, a brief discussion will be attempted of the technical aspects of this interesting group, their physical properties, etc., reserving for a later section mention of some current development work applied to aeronautical construction.

"Plastics" is a generic term given to amorphous substances, frequently resembling natural resins in appearance, and possessing the property of plasticity at some stage of manufacture; they are generally organic in the chemical sense and those which soften on heating usually do not melt sharply. They are divisible into two main classes:—(1) Thermoplastic, which soften on heating and set on cooling an indefinite number of times, and (2) Thermo-hardening, which change under the influence of heat to give infusible and insoluble forms which *cannot* again be rendered thermo-plastic; chemically, the essential difference between the two classes is explicable as a difference between the types of molecule present. The second class is that commonly used, in the form of hot pressure mouldings, to give materials of structural value, the former for other purposes, such as substitutes for glass, etc.

For aircraft purposes, plastic materials are being used, or are in process of development, for four main classes of component:—

1. Structural Parts, Airscrews, etc.

The phenolic thermo-hardening resins and compositions have received the greatest attention; the position in this and other fields was fully reviewed, in 1937, by de Bruyne.[34] Since that time, the development of this class of material has proceeded primarily along the lines of improvement of synthetic resins, reinforced with textile fibres or threads; as a result, considerably improved mechanical properties have been obtained.

[34] "Plastic Materials for Aircraft Construction." N. A. de Bruyne, Jour. Roy. Aero. Soc., Jan. 28, 1937.

2. Windows, Wind Shields, Instrument Covers, etc.

The transparent thermoplastics commonly employed are of methacrylate type; these appear to have replaced, to a great extent, cellulose acetate[35] and laminated glass. A widely-used commercial material of this type, has a constant refractive index of 1.50 and its light transmission qualities for thicknesses up to ¾in. are as good as for the best optical glass. The development of thicker sections, however, is more complicated and its use for prisms is not yet established; it is stable in dimensions and is not affected appreciably by water. Although about twice as hard as other available transparent resins, it is subject to scratching and has a fairly low softening point. Fig. 13 illustrates examples of the use of this material, which has a tensile strength of 7,200-8,700lb./inch^2, a specific gravity of 1.19 and coefficient of thermal expansion of 10^{-4} per °C. It is in general use for windscreens, turrets, windows, navigation lamp covers, also for the cock-pit covers of civil craft; in service machines, while the remainder of the cover may be of the synthetic material, the wind and sighting screens, where the greatest optical precision is required, are of laminated " safety " glass having an interlayer of cellulose acetate or other transparent plastic. Transparent products require development on the lines of cheapness, improved impact strengths, higher softening point, together with improved scratch resistance, surface hardness and resistance to moisture.

3. Adhesives, Glues, Cements, etc., Especially in Plywood.

These may contain a variety of resins; phenolics are common constituents but, recently, in one commonly-used type, urea resins have been applied very successfully. A reference to the improvements thus made possible in wooden construction has previously been made in the section on wood.

4. Coatings.

Many types of synthetic resins have been incorporated in coatings of various kinds. The colourless resins, *e.g.*, vinyl, alkyl, and chlorinated rubber, have been favoured, since their tendency to become yellow with age is small; special references to their properties and employment for wings of aircraft exist in the literature.[36 37 38 39]

The history of modern plastics began with the discovery of celluloid by Parkes in 1864; it can be described as semi-synthetic, being based on a naturally occurring material, cellulose, as is also cellulose acetate developed commercially since 1918. The vast industrial development of phenolic plastics dates from about 1908 with the appearance of Baekeland's patents, which first showed how the property of heat-hardening could be applied in practice. His method consisted of impregnating fibrous material with a phenolic resin and subsequently moulding under heat and pressure so that an insoluble and infusible product of considerable mechanical strength resulted. In essence, this moulded composition, or a similar one made by bonding together fabric or paper impregnated with resin, is the basis of organic structural materials. Moulded phenolics suffer from disadvantages of a comparatively high density, compared with wood, brittleness, and a low value of Young's Modulus (E) and the greatest field of development appears to be with the laminated materials.

In the event of difficulties in obtaining phenols, urea-formaldehyde plastics may be available, since urea is made by the combination, under high pressure, of the readily obtainable carbon-dioxide and ammonia; the properties of urea or

[35] " Study of Transparent Plastics for use in Aircraft." B. M. Axilrod and G. M. Kline, Bur. Stds. Res. Paper, RP.1031, Oct., 1937.
[36] Whitemore, M. R. Ind. Eng. Chem., 1933, 25, 19.
[37] McCloud, J. L. Ind. Eng. Chem., 1931, 23, 1334.
[38] Gardner, H. A. Proc. A.S.T.M., 1930, 33, 37.
[39] Kline, G. M. Bur. Stds. Res. Paper, RP.974, Feb., 1937.

amino plastics closely resemble those of phenolics. Cheapness may be brought about by the development of new plastics from such substances as Lignin[40] or Gambier.[41]

Some difficulty has been experienced in presenting the available data, relating to plastic materials of aircraft interest, in a logical and connected form. To begin with, we have the synthetic resin base; it is a truly plastic material, brittle under tension forces while its compression strength must be dependent on the time of application of the load. A figure of 5,000-6,000lb./inch^2 may be taken as the approximate tensile strength of the material. In a compression test of fairly short duration, the material will suddenly shatter at a value of approximately 21,000-24,000lb./inch^2. If the resin is now loaded with a powdered filler, *e.g.*, with wood flour as in the original phenol formaldehyde moulding powder, the compressive strength is a function of the amount of filler, the tensile strength is improved, but is still low; data are given in the paper by Dr. de Bruyne. Neither of these classes of material has any particular aircraft interest.

The next stage is the attempt to obtain greatly increased tensile strengths by the use of a continuous reinforcement and at once the material becomes invested with marked directional properties. Various reinforcing materials are used, mainly of the fabric or cord type and the strength properties in different directions may vary from a high value to the lower limit of the resin base itself. The maximum strength figures obtained, quite recently, relate to a resin reinforced with flax cord, which, in the direction of the cords, gave tensile, compressive and shear strengths of 69,400, 30,200 and 2,000lb./in.^{2} respectively, a value of Young's Modulus E (tension) of 7.4×10^6lb./inch^2, and a specific gravity of 1.45. These figures are not related; it is possible to give an improved compressive strength at the expense of the tensile strength or a reduced compressive strength with an increased tensile and value of Young's Modulus; again, the shear value quoted, 2,000lb./in.^{2} is low, a normal value for a material of lower tensile strength would be between 6,000 and 10,000lb./in.^{2}. The mechanical properties of the material will also obviously depend on the regularity and packing of the reinforcement; an excess of resin leads to brittleness and low tensile and shear strengths. These remarks are made to act as a warning against applying, without careful consideration, the results of test data for design purposes other than those for which the material may have been specially prepared; again, incomplete test data may be really dangerous in yielding an estimate of the suitability of a plastic material for a desired purpose. Subject to the above remarks, some test data acquired from a variety of sources may be presented.

Reference may first be made to a special type of material, made from a cellulose fluff impregnated with a phenolic resin. The " raw material " is in the form of thin cardboard-like sheets and is moulded into the required form under a pressure of 2 tons/inch^2 at a temperature of 150°C. Recent tests made on boards of the final product gave the following average results:—Tensile strength 20,000lb./inch^2, compression strength 22,500lb./inch^2, shear strength 7,000lb./inch^2, value of E. 1.97×10^6lb./inch^2, 0.1 per cent. proof stress, 12,500lb./inch^2, specific gravity 1.39. This material, which is of foreign origin, is being experimented with in this country for the development of moulded wings, fuselage and tailplanes.

Another moulding material, used for a variety of non-stressed aircraft components, consists of the usual phenolic resin with cotton, paper pulp fibre, and, in special cases, fabric reinforcement, and approaches some laminated materials in strength and shock resisting properties. Average test data are:—Tensile strength 15,000-22,500lb./in.^{2}, compression strength 25,000-45,000lb./in.^{2}, Young's Modulus $1.0\text{-}1.5 \times 10^6$lb./in.^{2}, specific gravity 1.34-1.38. This material is used for control units, acorns for separating stay wires, control pulleys, etc. It finds an important use in a bush fitted to the hub of adjustable pitch propellers to

[40] Kline, G. M. Modern Plastics, 1937, 14 (8), 41.
[41] Morgan, G. T. Chem. & Ind., 1938, 57, 9.

TABLE VI.

MECHANICAL PROPERTIES OF SOME REINFORCED SYNTHETIC RESINS.

Reference	General Description	Density lb./ft.³	Tension Max. Stress lb./in.²	Tension E. lb./in.² ×10⁻⁶	Compression Max. Stress lb./in.²	Shear Max. Stress lb./in.²	Shear N. lb./in.² ×10⁻⁶
A	Fabric Reinforced. Square Weave	84.4	10,000	1.07	26,600	6,500	0.35
		83.2	10,300	0.77	25,030	8,150	—
		85.5	12,080	1.21	27,570	10,600	—
		84.0	16,200	1.43	—	10,500	0.36
		83.1	18,000	1.53	23,000	6,500	—
		85.3	26,350	1.80	—	—	0.39
		85.5	28,600	1.81	—	10,600	0.45
	Cord Reinforcement	86.2	23,000	5.9	15,200	3,680	—
		84.4	27,500	1.81	27,000	6,500	0.30
		84.4	35,000	6.9	25,000	5,000	—
	Fabric and Cord Reinforcement	85.6	28,600	1.8	—	7,960	—
	Bonded Paper (Plane of Sheet: long. dir.)	84.7	12,150	1.25	—	—	—
	(Plane of Sheet: trans. dir.)	84.7	23,000	2.4	—	—	—
B	Cord Reinforcement	84.0	35,000	3.5	25,000	6,000	—
		88.0	37,000	5.2	18,000	5,000	—
		90.6	55,000	5.8	23,550	—	—
		87.3	69,400	7.5	—	2,000	—
C	Impregnated Cellulose Fluff	86.9	22,000	2.1	22,500	7,000	—

provide very hard locking and to prevent " fretting " between the blade and the hub; for this purpose, the reinforcement takes the form of a fine Egyptian cambric.

Some representative mechanical properties of various plastic materials are given in Table VI; all are derived from tests made in independent laboratories. Those included in the group marked A are commercial materials, commonly used in the electrical and other industries, but also employed for non-stressed parts in aircraft. The four materials of group B are materials specially developed for experimental airscrews; these are not commercially obtainable. The material C is that previously referred to as being used for the experimental development of moulded structural aircraft parts; developed for the electrical industry, it has not yet been used for the commercial production of aircraft components of any kind.

A note of general warning should be sounded with regard to the interpretation of mere figures of mechanical strength relating to plastic materials. Such figures should always be considered in relation to the *water absorption* of the materials. It is comparatively easy to obtain high tensile strengths and high values of Young's Modulus (E) by a reduction in resin content. But such reductions greatly lessen the resistance to water absorption and generally result in the material undergoing a considerable change in size, even to the extent of disintegrating when loads are applied.

Plastic materials, like metal and wood, exhibit fatigue characteristics. As an example, a fabric reinforced resin, density 82.5lb./ft.^{3} and tensile strength (longitudinal) of 14,600lb./inch^2, developed a Wohler endurance limit (10^7 cycles) of $\pm$5,800lb./inch^2. Absurd claims have been made regarding the fatigue resistance of plastic materials, due to a confusion of fatigue resistance and damping capacity (or strain hysteresis); they *do* possess good " damping " characteristics, also low water absorption and marked resistance to corrosion, while the values of specific tenacity associated with the stronger types compare favourably with some metals of construction. Their resistance to repeated impacts has been shown[42] to be good compared with aluminium alloys. The low torsional rigidity is a distinct disadvantage while certain materials of this general class exhibit marked " notch sensitivity " at stress concentrations due to holes, changes of section, etc. Plastic materials are often described as possessing great stability and, if this term is used to denote permanence of dimensions in the unstressed state, even when subjected to humidity changes, it is justified. Under prolonged stressing, however, these materials exhibit " creep " effects which may be important in certain applications. Static tensile creep tests have been made on a fabric reinforced synthetic whose short-time tensile strength was 16,000lb./inch^2; a series of specimens were then loaded at lower stresses. The results indicated that the material would probably withstand, without fracture for a very long period, a tensile stress of 12,000lb./inch^2, *i.e.*, $\frac{3}{4}$ of its normal quoted strength. The tensile load elongation curves for these plastics usually show definite permanent sets at lower values—in relation to their tensile strengths—than most metals and the hard woods. The problem of making successful joints in these materials by adhesives is not yet solved, although promising results are being obtained. Mention is often made of the potential uses of these plastics for bearings but it seems rather unlikely that they will ever be suitable for the principal bearings of aircraft; those interested in bearings for other purposes may be referred to recent papers.[43]

The future may bring forth many interesting applications, for aircraft purposes, of plastic materials in stress-bearing parts; research and development are being actively pursued. It may be *possible*, ultimately, to mould large sections of fuselage and wings in one operation, as the capacity of moulding equipment is

[42] See Fig. 25. N. A. de Bruyne, ibid.

[43] Proc. Inst. Mech. Engrs. General Discussion on Lubrication, Oct., 1937, Vol. 1. Papers by P. Beuerlein (p. 8), by G. R. Eyssen (p. 84), by H. W. Rowell (p. 266) and E. W. Smyth (p. 277).

constantly increasing, although to make such a method economical the number of parts required would have to be very large. But the *present* position should not be presented in too enthusiastic terms; in discussing recently the whole subject of aircraft plastics with a keen believer in its future, he remarked " plastics show more promise than performance " and the remark aptly describes the present position.

E. Methods of Surface Protection.

Adequate surface protection against wear and corrosion is an urgent requirement in aircraft materials because of the heavy duty demanded of engine parts and because of the relative thinness of structural components exposed to severe climatic conditions. The subject is most extensive but it may be useful to include a brief note on some of the methods in current use; more adequate treatments will be found elsewhere.[44] [45] [46] [47] [48] [49]

With regard to resistance against *wear*, the use of nitrided steel surfaces is perhaps the most outstanding example. The process consists of heating the steel in an atmosphere of ammonia at about 500°C. whereby the ammonia is dissociated, nitrogen entering the surface of the steel producing intense hardness (often exceeding 1,000 V.P.H.) due to the formation of nitrides. Its principal use is for crankshafts and valves where the conferred hardness and wear-resisting properties are so valuable. Less obvious is the fact that the fatigue resistance to flexural and torsional, *not* axial, stressing is so greatly increased and this even when serious stress concentration effects are present. Of the facts there is no doubt; practical experience of aero engine crankshaft performance demonstrates the actual improvement gained, fully confirmed by many independent laboratory experiments, many of which have been summarised by Sutton,[50] who cites examples of the effect of notches, fillets and threads. A recent experimental result, relating to a shaft pierced by a radial oil hole may illustrate the general effect and also be of special interest. The shaft material gave a flexural limiting fatigue range of $\pm 32\frac{3}{4}$ tons/inch^2; the addition of a nitrided case of normal thickness raised this value to $\pm 47\frac{1}{2}$ tons/inch^2, an increase of 45 per cent. When a radial oil hole was pierced, in the un-nitrided shaft, the fatigue range fell to $\pm 14\frac{3}{4}$, *i.e.*, to 45 per cent. of the original value, while exactly similar shafts, with oil hole *and* nitriding surface, gave a fatigue limit of $\pm 26\frac{1}{4}$, an improvement of 78 per cent. due to the nitriding. It is suggested that the explanation of this curious result is as follows. In the first place, in a plain and nitrided shaft, fatigue failure begins at the *interface* of the nitrided layer and the core material; of this, the typical appearance of such fractures leaves no doubt. Now when the oil hole is present, the stress concentration effect on the steel itself reduces the resistance by 2.2 times, as shown by the experimental result quoted above. When the nitrided surface is pierced by the hole, the stress concentration in that very hard casing must almost certainly be greater than 2.2, but the intrinsic fatigue resistance of the nitrided surface is probably so high that the shaft still fails by fatigue at the interface; hence the resistance of the pierced shaft *as a whole* is actually increased. This point has been discussed in some detail because the greater immunity against fatigue conferred by a nitrided surface, which has led to its almost universal adoption in aero engines, is really an unexpected and curious result. Incidentally, the greatly increased intrinsic

[44] Use of Light Alloys in Aircraft from the point of view of Corrosion. H. Sutton, Jour. Roy. Aero. Soc., 1929.
[45] Protection of Metal Parts of Aircraft against Corrosion. H. Sutton, Jour. Roy. Aero. Soc., Vol. 36, 1932, pp. 1/23.
[46] Aitchison, L. Jour. Roy. Aero. Soc., 1934.
[47] Bengough, G. D., and Whitby. Jour. Roy. Aero. Soc., 1935.
[48] Magnesium Alloys. C. H. Desch, Jour. Roy. Aero. Soc., Vol. XLI, 1937.
[49] Alloys of the Light Metals. C. H. Desch. Jour. Soc. Chem. Ind., March, 1938, Vol. LVII.
[50] Fatigue Properties of Nitrided Steel. H. Sutton, Metal Treatment, Summer, 1936.

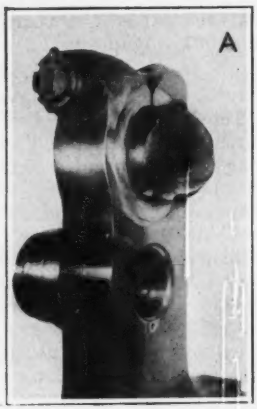
hardness conferred on the surface has given a much longer life to crankshafts used in conjunction with lead-bronze bearings.

The old-established practice of case-hardening is still widely employed; in this process, the marked modern improvement has been effected with regard to the steels now available. Chromium plating is also extensively employed to reduce wear of steel parts, such as valve rocker tips, also in places where abrasion and corrosive influences are combined, as in hydraulic jacks, landing gear, etc. Reference has previously been made to the severe conditions of the valve seating where " stelliting," also a covering of 80-20 Ni.-Cr. alloy find such valuable applications.

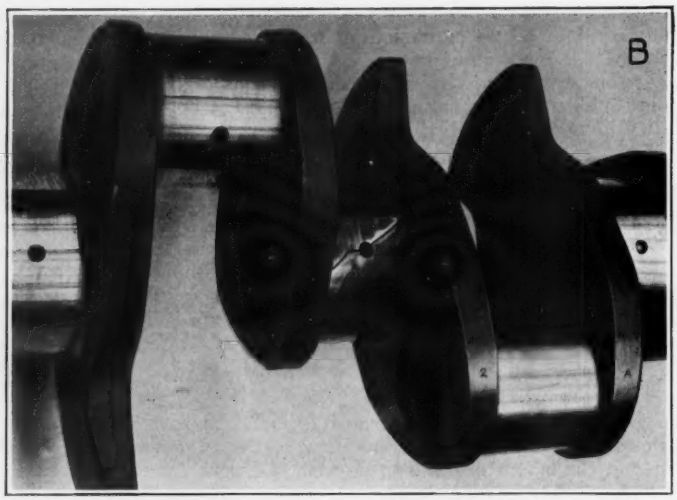
The protection of aircraft parts against *corrosion* opens up a most fascinating field to which extensive research has been and is still being directed. Perhaps the outstanding feature in recent years of research into the fundamental aspects of corrosion has been the demonstration of the importance of thin surface films of reaction product, frequently of oxide or hydroxide. In the case of atmospheric corrosion, invisible oxide films have been shown to give marked protection against the tarnishing of certain non-ferrous metals and alloys in polluted atmospheres and to be responsible for the corrosion resistance of stainless steels. Whilst gravimetric methods have been mainly responsible, various other techniques have been applied to the study of these thin films, *e.g.*, the use of polarised light, photo-electrical, electrical, chemical, and electron-diffraction methods. As a result, a much better understanding is now being obtained of the fundamental aspects of corrosion phenomena. Technical processes for the protection of metals frequently consist in the rapid production of films of reaction product which stifle further attack and prevent access of the atmosphere or liquid to the metal; the best known example is the Bengough-Stuart process of anodic oxidation of aluminium and its alloys, so extensively used for aircraft purposes. Further interesting examples are provided by the protection of magnesium by selenium coatings and by the addition of aluminium to brass giving a surface film having enhanced resistance to corrosion; this field is by no means exhausted and further developments are to be expected. A further line of profitable investigation is the treatment of the environment, as distinct from the metal, with a view to modifying the corrosion mechanism; an example is provided by the quinoline process for the protection of magnesium alloys against corrosion by leaded petrol fuels. As distinct from corrosion that is confined to the surface of the material, there is a further type characterised by inter-crystalline penetration and embrittlement. Under certain circumstances, two widely used materials, viz., alloys of the duralumin type and austenitic stainless steels, exhibit a tendency towards this mode of failure. Unsuitable quenching conditions in final heat treatment, for example, may produce this tendency in duralumin, whilst exposure to temperatures within a certain range may also induce a similar susceptibility in austenitic stainless steels. In each case, considerable progress has been made in avoiding this type of attack, either by special care in heat treatment or by small additions to the alloy.

Cadmium electro deposits give satisfactory protection against corrosion to such parts as steel cylinder barrels, light alloy cylinder heads, streamline wires, etc. Zinc coatings, applied either by electro deposition or by the hot diffusion or " sherardising " method, find useful applications in the protection of steel tubes and fittings. Nickel-plating, aluminium spraying and aluminium dipping are used to protect steels against oxidation at elevated temperatures. Undoubtedly, the greatest advance made in the protection of aluminium alloys for structural purposes has been in the development of the " clad " sheets, in which the alloy is covered by a coating of very pure aluminium. For manganese alloys, the most effective and widely used form of protection is a protective film provided by a chromate treatment; this is supplemented by oil or cellulose enamels where severe conditions are to be provided against; the application of anodic oxidation treatment to magnesium alloys is in the development stage but not yet used exten-

the effect, on fatigue resistance, of various *surface finishes*, such as plating, blasting and coatings; some work of this type is already in hand, but the field is wide.



A. Crankpin failure commencing at grinding cracks.



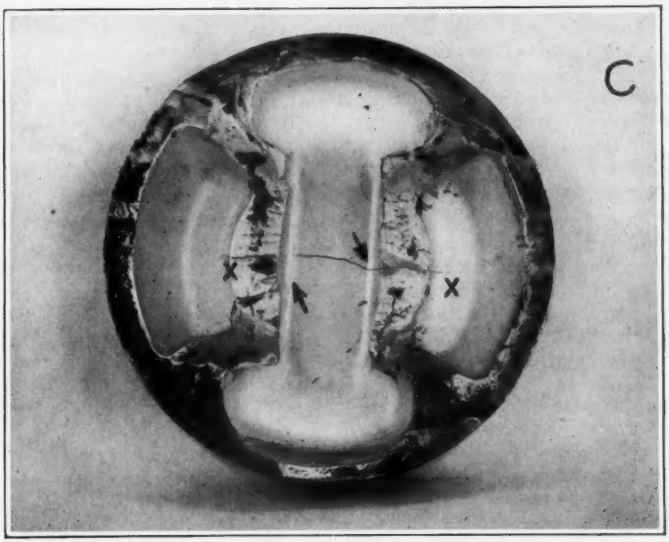
B. Crankshaft failure commencing at oil hole.

FIG. 21.
Failures.

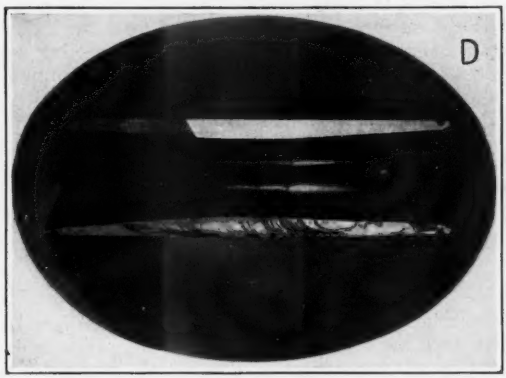
From this general discussion, attention may now be turned to the special problems of certain selected components. Certain failures will be referred to and, to avoid any mistaken conclusions regarding the reliability of engines in service, it should be clearly understood that these failures have been obtained under test overload conditions, chiefly carried out for development purposes.

1. PISTONS.

Pistons of the present aero engines in production are exclusively of aluminium alloys, chiefly of " RR59 " or " Y " alloys; these materials provide good strength



C. Piston failure by flexing action.



D. Gudgeon pin bending failure commencing at inner surface due to local defect.

FIG. 21.

Failures.

at high temperatures allied with the requisite thermal conductivity. Much attention is being given to the experimental development of Mg. alloy pistons and satisfactory pistons of this type may be evolved in the future. There is little

doubt that the aluminium alloy piston is at its peak of development for the air-cooled type of engine, being liable to fatigue and softening at high temperature; the imposed piston inertia forces are considerable and the use of a lighter and stronger alloy would offer great opportunities for further engine development by allowing still higher piston speeds to be employed. In an air-cooled engine, the effects of softening and fatigue are additive; this is also true, to some extent, in the liquid-cooled engine, but, owing to the lower running temperature, the fatigue aspect, as such, assumes greater importance. The most common form of failure in both types is by cracking at the inner face of the head, at the junction of the gudgeon pin boss with the crown, due to flexing fatigue action; failures also occur at the top of the gudgeon pin bore. A typical example of the former type is illustrated in Fig. 21c; failure commenced with the long horizontal crack marked XX, while subsidiary cracks are visible at the transition radii of the boss.

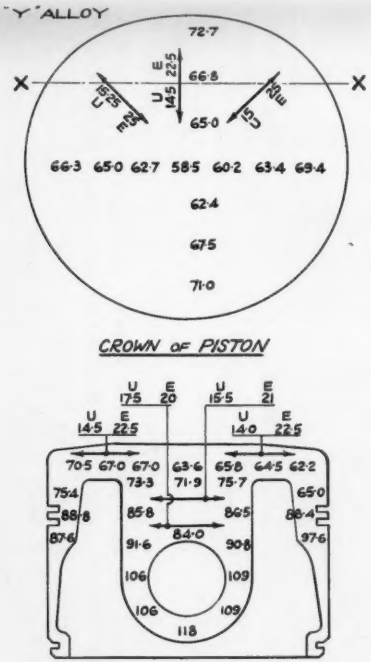
Present improvement in aluminium alloy pistons chiefly takes the form of design aimed at a better heat flow and one method adopted is of great interest. It consists of cutting up pistons into a number of pieces and determining the changes in hardness or tensile strength that have resulted from prolonged exposure to the operating conditions in the engine. Referring to Fig. 22, the left hand pair of diagrams, relating to a piston of "Y" alloy, illustrate the nature and amount of softening that has taken place. The hardness values vary from 118 to as low as 58½, while the tensile strength and ductility values also show marked deterioration. The influence of the form of the piston on the heat flow, and consequent softening of the alloy, is evident. By soaking test pieces in a furnace at various temperatures, curves are obtained which relate the degree of softening with time at these temperatures. Such curves, relating to RR59 alloy, are reproduced in the top right hand diagram of Fig. 22; it will be observed that each curve tends to become asymptotic to a line representing a certain hardness number and, in this way, the prevailing temperature at any point in a piston, following prolonged service, can be directly deduced. Thus, in the three piston sections shown in the centre of Fig. 22, the temperature zones are indicated by dotted lines and it is reasonable to assume that the directions of heat flow will be normal to these lines. Therefore, where the zone lines make an acute angle with the surface in the direction of flow, an indication is afforded that heat is flowing out through the surface due to some cooling agency; where the zone lines are normal to the surface, no cooling action is taking place. In this most interesting manner, the regions of high temperature and directions of heat flow are indicated. As the result of such examinations, new and improved piston designs have been produced in which the hottest zone, F, has been entirely eliminated and the zone E is very uniform over the centre portion of the piston crown, in no place extending to the periphery.

It is thus made clear that, as in present pistons, the properties of the available materials have been fully utilised, the development of improved forged alloys having increased fatigue resistance at 200-400°C. would be a most valuable advance.

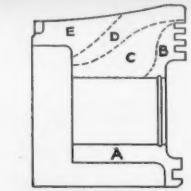
Failures of piston gudgeon pins, usually made of case-hardened nickel-chromium steel, are extremely rare even under severe overload; Fig. 21d shows the type of fracture obtained, due to bending fatigue action, commencing at the inside surface at a defect. Failures of piston rings, as such, are comparatively rare, but a considerable amount of piston ring research is being carried out both at home and abroad; this most important component is made of cast iron either of the ordinary or alloy type.

2. Bearings.

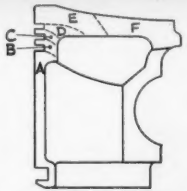
White metal bearings were, at one time, universally employed; at the present time, they are still employed to a certain extent, but lead-bronze bearings have entirely superseded them in a large number of engines. The reason is, of course,



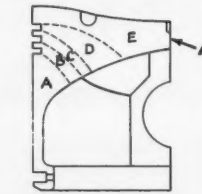
FIGURES GIVEN SHOW VICKERS DIAMOND HARDNESS VALUES, & ARROWS INDICATE POSITIONS OF TENSOMETER TEST PIECES.



SECTION THROUGH GUDGEON PIN BOSS.



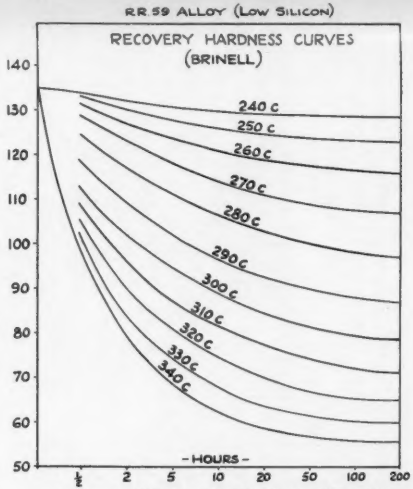
SECTION THRO' PLANE PARALLEL & IMMEDIATELY ADJACENT TO WIDE TRANSVERSE WEB.



SECTION THROUGH WIDE TRANSVERSE WEB

NOTE: CENTRE OF CROWN IS COOLER THAN ZONES IMMEDIATELY BEFORE & BEHIND (AS SHOWN ABOVE) DUE TO HEAT CONDUCTION THROUGH TRANSVERSE WEB.

DIAGRAM ILLUSTRATING SOFTENING AND TECHNIQUE FOR DEDUCTION OF HEAT FLOW IN PISTONS UNDER RUNNING CONDITIONS BY METHOD OF HARDNESS SURVEY



CURVES SHOWING HARDNESS OF MATERIAL AFTER SOAKING AT CONSTANT TEMPERATURE.

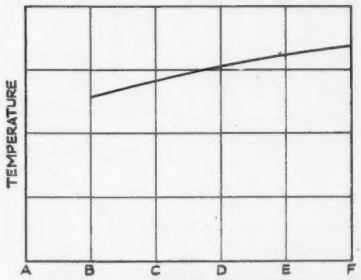
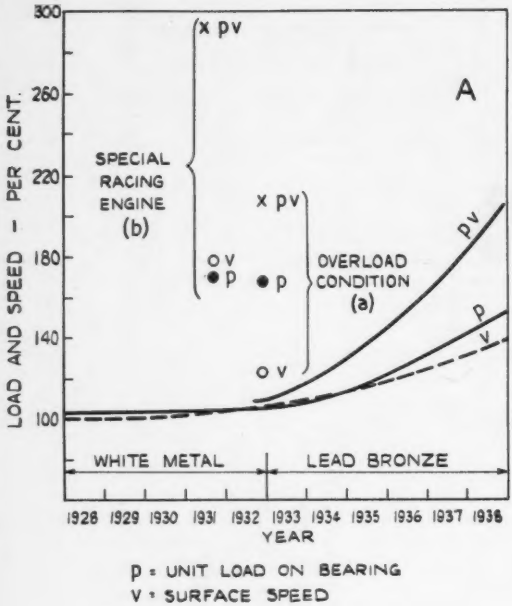
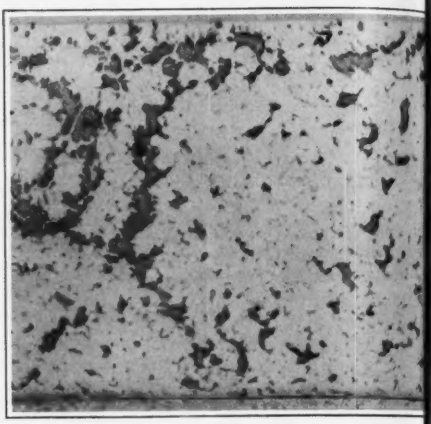


DIAGRAM SHOWING DEDUCED TEMPERATURES OF ZONES

FIG. 22.



B



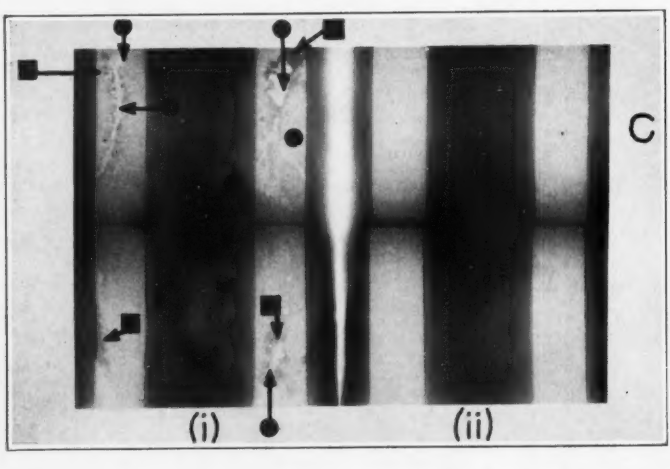


FIG. 23.

Bearings.

A. Increase of load and speed in big end bearings.

B. Lead bronze bearing: Microphotograph showing lead segregation.

C. Radiographs of lead bronze bearings.

(i) Porosity ● , lead segregation ■

(ii) A satisfactory bearing.

the increased duty now demanded, marked increases having occurred in the surface speeds and bearing pressures used. Also the operational temperatures have increased to the point where the fatigue strength of the white metal is seriously impaired. This development, with the resulting change in bearing material is illustrated in Fig. 23a relating to certain well-known engines and covering the period 1928-1938. It will be observed that, in 1938, the *pv* curve is still rising rapidly and reveals the urgent need for further improvements in the bearing materials now available. Before leaving this curve it may be remarked that the bearings of standard production engines will still run satisfactorily under overload conditions for a limited life; the points marked (*a*) refer to such a test, while those marked (*b*) relate to a racing engine for which a life of $5\frac{1}{2}$ hours only was necessary.

Some lead-bronze bearings for big-ends are still centrifugally cast, static casting being employed for main bearings, but it seems probable that static casting may be used exclusively in the future. The performance of lead-bronze bearings is, in general, quite satisfactory; insufficient adhesion to the backing is still sometimes encountered, but usually, when trouble is met it arises from surface fatigue at high spots, as lead-bronze does not appear to possess that property of "spreading," so desirable in a bearing material to allow even distribution of loading pressure. Failures, although rare, are inconsistent, reasons for the failure often not being apparent, although the marked sensitivity of lead-bronze to poor lubrication conditions is probably responsible; thus, the lead-bronze bearing is often described as "fussy." It is established practice now to take an X-ray radiograph of every bearing put into service; this, in combination with a careful service record, has led to most satisfactory laboratory control in production, resulting in good service performance. Lead segregation is most carefully watched for, as indicative of poor adhesion between the bronze and the steel liner, and a likely source of trouble. The microphotograph of Fig. 23b shows an example of such segregation, resulting from faulty casting methods. The radiograph of Fig. 23c (i) illustrates defects of porosity and lead segregation, while that of Fig. 23c (ii) represents a satisfactory bearing. Lead-bronze bearings sometimes exhibit "scratching," while a diminution in the supply of lubricant, leading to a rise of temperature, will often cause "lead sweat," the lead being melted out of the bearing. The hardness of these bearings has necessitated the use of harder shafts; nitrided shafts work particularly well with lead-bronze.

Although, as stated above, lead-bronze bearings, when carefully made, give satisfactory performance in the present engines, the search for other materials is being vigorously pursued. Much research has been carried out with aluminium base alloys and Devereux[54] writes enthusiastically of a recently developed alloy consisting of 90 per cent. Al. with additions of Sn., Sb., Ni., Mn., and Si. Bearings of this alloy, run side-by-side with others of lead-bronze and white metal under experimental conditions, exhibited lower friction and less liability to seizure; it is understood that this alloy has now been successfully used in aero engines. Cadmium base bearings, containing nickel and silver are also being tried in this country, but are subject to corrosion by the organic acid compounds usually present in the lubricant; this trouble may be overcome by co-operation with the suppliers of the oil. It is also understood that extensive experiments on bearings made of high purity *silver* are in progress in the U.S.A.; laboratory tests are stated to have shown that these silver bearings exhibit marked resistance to fatigue combined with rather remarkable freedom from seizure.

Bearing pressures up to 5,000lb./in.^{2} and rubbing velocities of 2,500ft./minute are now being reached and further increases may be regarded as certain, provided satisfactory bearing materials are developed; such materials would enable the use

[54] "The Use of Light Alloys in Modern Design." W. C. Devereux, Jour. Inst. Auto. Engrs., No. 5, Vol. VI, Feb., 1938.

of higher engine speed and, possibly, of larger diameter pistons, thus leading to an improvement in power-weight ratio. Lead-bronze bearings will not meet these demands of the future and a most useful field for research is evident.

3. VALVES.

The poppet valve in present use represents a most remarkable metallurgical development designed to withstand extreme severity of operating conditions of high temperature (750°C.-850°C.) and exposure to the corrosive action of leaded fuels, combined with the need for cooling by heat transference. The present answer is the hollow sodium-cooled valve, made of an austenitic steel containing 13 per cent. Ni., 13 per cent. Cr., 2½ per cent. W., the stem usually being nitrided, the seating ring covered with stellite, an alloy of Co., Cr., and W., while the head, and in some cases the seating also, is covered with an 80-20 Ni. Cr. alloy. The advent of this construction was hailed as an adequate answer to the valve problem. However, certain troubles are still sometimes encountered. Differential expansion between the materials of the head and covering may lead to serious cracking, a difficulty so likely to arise in a composite component; some development may take place in the direction of making the complete valve of the 80-20 Ni. Cr. alloy. In the air-cooled engine, the chief problem arises from the corrosive attack of the combustion products, particularly at the junction of the head and stem. At the operating temperature, the austenitic condition of the steel is not stable, and is likely to break down from the " γ " to the " α " phase, in which condition it is much more susceptible to corrosion; this breakdown has been established by microscopical examination of the structure of valves taken from service. The nitrided surface is liable to flaking, the accumulated flakes and corrosion products sometimes causing seizure. In spite of such occasional troubles, the poppet valve material is fairly satisfactory for present engines. But it seems likely that future direction of valve development for higher powered engines, particularly of the air-cooled type, will tend more and more towards the sleeve valve, although special difficulties relating to materials have to be overcome. Advantages claimed for the sleeve valve include reduced fuel and oil consumption, reduced mechanical and exhaust noise, much simpler mechanism with corresponding easier maintenance, but most important of all, the evolution of a valve which will withstand successfully the further increase in engine speed and the use of still higher octane fuels for which the present poppet valve is deemed to be unsuitable. The first sleeve-valved radial engine produced in this country successfully emerged from its trials in 1933 and progressive development has led to the engine shown in Fig. 9a.

The use of a nickel-chromium-manganese steel, having a high coefficient of thermal expansion (0.000022) approximately equal to that of the light alloy cylinder head, has been previously referred to; it is most successfully applied to air-cooled engines. But the special circumstances met with in different types of engines—and the difficulty of making general statements—is revealed by the experience encountered in one type of liquid-cooled engine where the use of high expansion steel actually caused such distortion of the valve insert seating that the inserts became loose after a short run; the valve insert material was successfully changed to a silicon-chromium steel having a *lower* coefficient of expansion.

Valve spring failure, by fatigue, is still sufficiently frequent as to be a nuisance. There is no standard practice throughout the industry, various materials being used; a hard-drawn carbon steel, containing 0.7-0.8 per cent. C. and not greater than 1 per cent. Mn. is used in some practice; a steel containing 0.4-0.5 per cent. C., 1-1.5 per cent. Cr., and a minimum of 0.15 per cent. V., wound soft and subsequently heat-treated, is also employed; these materials develop a tensile strength of 90-120 tons/in.^{2}. The presence of surface defects must be guarded against and a rigid control of magnetic testing has proved most useful in this connection. At one time, rejections amounted to as high as 30 per cent., but the practice of using ground wire, cadmium plating and testing has reduced this, nowadays,

to a usual figure of between 3 and 4 per cent. Although the design stress is high, the principal trouble arises from surging; by the use of closed end coils and design generally, every effort is made to avoid harmful effects due to surging by damping, but the difficulty of the problem is indicated by some typical figures.

Engine Operating Condition.	Frequency of Valve Spring Operation.
Idling	300 c.p.m.
Normal Flight	1700-2200 c.p.m.
Power Dive	2400 c.p.m.

An improved fatigue strength is greatly desired. In this connection mention may be made of experience gained in the automobile engine, where the conditions are at least as onerous, as far as the spring is concerned. Much experience has been gained of the improvement achieved by the use of a heat-treated spring steel made from Swedish ore of high purity; failures of these springs, attributable to faulty material, in automobile engines during the past four years are estimated at less than one in a million springs. The material is a 0.65-0.7 per cent. C. steel, oil hardened and tempered, *before coiling*, to give a minimum U.T.S. of 90 tons/in.^{2} and an elongation of 8 per cent.; the springs are shot-blasted for 30 minutes, using 1/32in. dia. shot and 20lb/in.^{2} air pressure; tests have shown that the surface work-hardening thus obtained yields an increase in fatigue strength of up to 25 per cent. It is understood that such springs are being experimented with for aero engine purposes.

4. CRANKSHAFTS.

Crankshaft design may be said to be controlled chiefly by consideration of the permissible bearing pressures and, in the case of in-line engines, the necessity for providing sufficient rigidity to keep deflection within the limits required for providing an even distribution of bearing pressure. Where the number of cylinders on in-line engines is small, the rigidity has also to be related to the avoidance of torsional vibration trouble. The latter considerations usually imply that the dimensions of crankshafts for in-line engines are fixed by considerations of stiffness rather than strength, although, by careful design, it is sometimes possible to utilise to the full the mechanical properties of the material and, at the same time, provide the requisite stiffness; for example, by using hollow pins and journals and removing superfluous material in the webs. Many modern crankshafts are nitrided all over, the principal steel used being a 55-65-ton nickel-chromium-molybdenum steel (1 per cent. Ni., 0.5-1.5 per cent. Cr., 0.9-1.5 Mo.), while a 60-70 tons high chromium-molybdenum steel (2.5-3.5 per cent. Cr., 0.3-0.7 per cent. Mo.) is also popular. The use of a nitrided surface provides, in the first place, an excellent combination with the lead-bronze bearing; equally important, is the greatly increased fatigue strength conferred, particularly in the region of stress-concentrations due to keyways, oil-holes, fillets, screw threads, etc., this most interesting aspect has been previously discussed; it is considered desirable that the nitriding should extend over the whole of the shaft including webs; the thickness of the nitrided layer used varies from 0.012in. to 0.03in. As in similar components, a satisfactory grain flow throughout the shaft is of great importance, also, the need for the maintenance of a high standard of cleanliness in the steel.

Crankshaft failures in service are practically unknown and it is necessary to resort to tests under high overload conditions to reveal that the weakest part of the shaft is at regions subject to stress-concentrations. Fig. 21b shows the result of such a development test made on an in-line engine; the failure, starting at the oil-hole, has spread over both the adjoining webs. Fig. 21a is a failure caused by circumferential grinding cracks in the crankpin of a radial engine.

The chief need of the engine designer in relation to crankshafts relates not so much to improved materials of construction—although a steel having a much higher damping capacity would be welcomed—but for experimental data of the

effect on the fatigue resistance of the usual form of stress-concentrations encountered, taking into account both the *form* of the discontinuity *and* the material. These tests should include some made on full-sized specimens, as the problem of " scale effect " is still obscure and is very important; they should

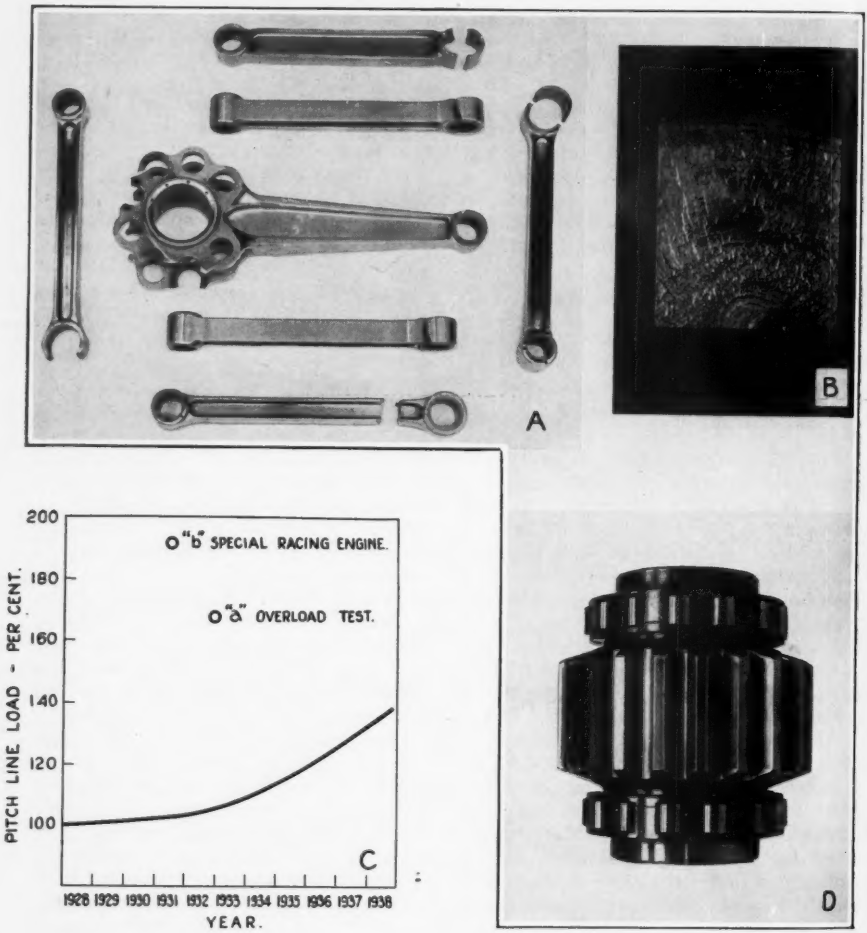


FIG. 24.

A. Various types of failure in connecting rod assembly.
B. Eye of master-rod; failure started by " fretting."
C. Diagram illustrating increase of gear tooth loading; period 1928-1938.
D. " Scruffed-up " reduction gear pinion.

also include consideration of the stress-concentration existing at the point where case-hardening or nitriding ends as more experimental data are required on the point as to whether it is really necessary to surface-harden the *whole* of the shaft surface including balance weights where these are formed integral with the shaft.

5. Connecting Rods.

These highly stressed components have, in the past, given much trouble during the course of their development but completely satisfactory designs have now been obtained. Materials used include a $3\frac{1}{2}$ per cent. nickel steel (55-65 tons/in.^{2}) and a $3\frac{1}{2}$ per cent.—0.5-1.3 per cent. nickel-chromium steel (65-75 tons/in.^{2}) for ordinary purposes, while master-rods may be made of an air-hardening nickel-chromium steel ($3\frac{3}{4}$-$4\frac{1}{2}$ per cent. Ni., 1-$1\frac{1}{2}$ per cent. Cr.) developing a tensile strength of 105 tons/in.^{2}; for the latter purpose, steels of the Cr.-Mo. type are also being tried out for development purposes. The service demanded of a master-rod is indeed severe, complicated by the stress conditions present in the " eyes " of the rod; in the shank, *e.g.*, the purely nominal cyclic stresses vary from, say, 10 tons/in.^{2} in compression to 8 tons/in.^{2} in tension, with a bending stress of 12 tons/in.^{2}, although the bending stress is negligible when the direct stresses reach their highest values. The nominal cyclic stresses in the articulated rods vary from 12 tons/in.^{2} compression to 8 tons/in.^{2} tension. Fig. 24a shows a variety of types of failures produced in tests to destruction made in a special connecting-rod fatigue testing machine. In components such as these subjected to oscillating motion, " fretting-corrosion " marks may act as the origin of fatigue failures: Fig. 24b shows the face of such a fracture. For the connecting rods of future engines of higher power, a 150-ton steel is required; as mentioned in Part III, Section A, such a steel is now available.

6. Gears.

As in the case of bearings, the severity of operating conditions has increased greatly in recent years. The curve of Fig. 24c indicates the changes in pitch line loading that have occurred during the past ten years; here again, gears will withstand, for a limited time, much greater loading than employed under operating conditions, as indicated by the point " a " in the diagram, the point " b " relating to a special racing engine required to have an effective life of $5\frac{1}{2}$ hours only. The material that is generally used for highly stressed gears is a nickel-chromium (4-$4\frac{1}{2}$ per cent. Ni., 1-1.6 per cent. Cr.) case-hardening steel; recent developments refer more to design than to improved materials, as far as *composition* goes, although great attention is devoted to the control of micro-structure and grain flow in the forged gear blanks. The induced bending stresses are very high, 60,000-80,000lb./inch^2, but it is due to the severe conditions of *surface* loading that trouble occurs, leading to " pick-up " and severe local wear on the gear contacts. It is considered that this may arise essentially from insufficient strength in the core material and a need exists for improvement in this direction. Cr.Mo. steels are being experimented with and offer promise. It may be noted that nitrided surfaces are useless; they will not stand up to the impact conditions. Fig. 24d is a most interesting example showing the trouble referred to. It relates to a reduction gear pinion, tested under overload conditions for experimental purposes; it " scruffed-up " badly after 130 hours' running. The driving sides of the teeth, seen on the left of the photograph, are badly " scruffed-up " and, on the third tooth, a marking can be seen at or near the pitch line where the case had cracked through. The non-drive sides of the teeth, seen on the right of the photograph, show light scruffing, from which it was found that insufficient back-lash had been allowed, so that the teeth were too deeply in mesh. This resulted in excessive tooth loading, giving the same effect as if the gear had been run under excessive torque. The material was the case-hardened nickel-chromium steel referred to above, the hardness of the core being 360-400 B.H.N. while that of the case was C.57-65 Rockwell.

The ability of the tooth surface to carry high line-loadings naturally depends greatly on the lubricating conditions but to an extent that may not be fully realised. An experiment carried out on a aero-engine reduction gear using, alternately, mineral and castor oils may be of interest. After two hours' running

with the mineral oil, all the signs of incipient break-down of the tooth surface were evident. The mineral oil was carefully removed and castor oil substituted; after a short run, the gear had again acquired a polished surface. This cycle was repeated again and again, with constant repetition of the healing-up and deterioration of the surface; at each stage, the relative lubricating value of each oil, under working conditions, was exhibited.

Cloud-burst hardening, on the same case-hardened steel of reduction gears, has been tried with most interesting results. The hardness (diamond-pyramid) of the case was increased from 670 to 950 (H_{D30}); it was also found that, after such cloud-burst hardening, the surface age-hardened by a further 10 per cent. within about 12 hours. Double cloud-burst hardening has been investigated, consisting of a second treatment applied after a rest of about 6 hours, when the hardness is stabilised at a higher figure, some 15 per cent. greater than that obtained by a single treatment. The method of cloud-burst hardening has also been applied to case-hardened valve-rockers.

It may be noted that fretting-corrosion has been encountered in gears shrunk on to shafts.

7. Crankcases.

The crankcase is to be considered as a stressed part, subjected to live loading at moderate temperatures, say, 100°-200°C. For engines up to a certain power, two magnesium alloys, containing 8½ per cent. Al., 3½ per cent. Zn., are used. Crankcases made of this material suffer from the inherent disadvantage of the low modulus (E) of magnesium alloys and, if sufficient material is used to give the necessary stiffness, the saving in weight, as compared with the use of an aluminium alloy, tends to disappear, while the other disadvantages of corrodibility, lower fatigue strength and increased notch sensitivity, remain. As a result, for engines of higher power, a change to an aluminium alloy is made. The aluminium alloys used for crankcases are either forged (RR56 type) or cast (RR50 type). In both cases, there is a demand for an improved material having a greater resistance to creep at temperatures of about 150°C., less sensitivity to stress concentration effects, while retaining the other good mechanical properties of the existing alloys. A most interesting experience arose in connection with the use of the forged alloy in the fully heat-treated condition. Failures were encountered and proved to be associated with the presence of internal stresses; experiments revealed that these internal stresses amounted to as much as 7 tons/inch² in direct stress, with 11 tons/inch² bending stress. Fig. 25a shows a crankcase failure due to this cause. As a result of this experience, practice was changed from the heat-treated alloy, having a tensile strength of 27 tons/inch², to the same material in the annealed condition, having a strength of 16 tons/inch² only, and satisfactory performance was obtained.

But the weight saving to be derived from the use of a satisfactory magnesium-rich alloy for crankcase purposes is everywhere recognised; the development of such an alloy, having good mechanical properties, improved resistance to creep at moderately high temperatures and, if possible, increased inherent resistance to corrosion, is one of the major requirements of the aircraft industry and its solution would contribute greatly to the development of the high-powered engines of the future. The recent development,[55] at the National Physical Laboratory, of magnesium alloys containing cerium, having improved creep characteristics, may contribute to this end, particularly with the application of the improved present-day forging methods.

8. Cylinder Heads.

Some difficulties have occurred owing to the cracking of the large casting forming the cylinder heads of in-line liquid cooled engines. These heads were rigidly

[55] "Magnesium and its Alloys." J. L. Haughton and W. E. Prytherch, H.M S.O., London, 1937.

connected together; temperature gradients gave rise to strains which, it was concluded, produced cracking, often of an inter-crystalline character, across valve seats, due to fatigue or creep in proportions not yet really understood. The trouble has been got over by design, isolating the heads allows the necessary freedom for expansion. But the problem discloses a need for improved aluminium alloys possessing increased resistance to fatigue and creep at elevated temperatures. In connection with the cylinder heads of air-cooled engines, improvements in the physical properties, within the temperature range of 200-400°C., would constitute a welcome advance.

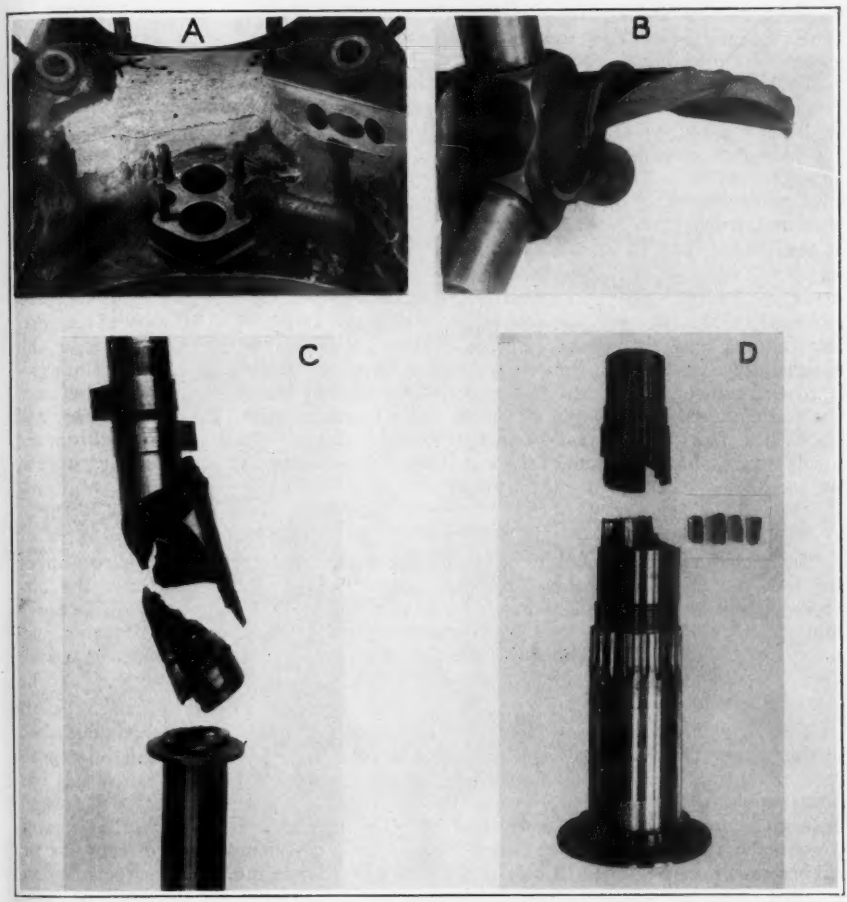


FIG. 25.

Failures.

A. Aluminium alloy crankcase: Failure due to internal stresses.
B. Steel airscrew shaft: Failure commenced at fretting on splines.
C. Steel camshaft: Failure due to torsional vibrations.
D. Steel "spring-drive" shaft: Failure due to shock loading and stress concentration.

9. SUPERCHARGERS.

The impeller is an important item, exposed to severe stressing conditions. A normal speed of rotation is 24,000 r.p.m., when the blades may be subjected to nominal direct stresses of 14 tons/inch^2 or more; they are, however, also subject to flutter and other vibration effects and such failures as occur are principally due to this cause. At present, impellers are made either of steel or aluminium alloy. Development in steel commenced with the use of a 65-ton nickel-chromium steel ($2\frac{3}{4}$-$3\frac{1}{2}$ per cent. Ni., 1-$1\frac{1}{2}$ per cent. Cr.) superseded by a 100-ton air-hardening steel ($3\frac{3}{4}$-$4\frac{1}{2}$ per cent. Ni., 1-$1\frac{1}{2}$ per cent. Cr.) which, proving too hard, has in turn been displaced by a 70-ton 5 per cent. nickel steel. In other engines, successful use is made of the RR56 aluminium alloy. The need for lighter materials still exists and stampings of magnesium-rich alloys are being used for experimental and development purposes. Although the impeller drive is designed to be highly elastic, the property of damping capacity is desirable in a material for impeller construction. The exhaust turbo-driven supercharger will introduce additional problems, as the temperature of the gases will be about 700-750°C. Operating at speeds up to 35,000 r.p.m., a satisfactory material would be required to withstand centrifugal stresses of 6 tons/in.^{2}, say, at 700°C. A steel having a high creep strength, allied with resistance to scaling and corrosive attack by the exhaust gases, is required and experiments on this problem are in hand.

Many other engine components, such as cam and propeller shafts, covers and castings, etc., present interesting problems relating to their materials of construction but most of these have really been covered, in a general manner, by the above discussion on other selected components. Three photographs of interesting failures may be added: Fig. 25b shows a broken airscrew shaft in which fatigue fracture has commenced from fretting on splines: Fig. 25c is of a case-hardened camshaft, of 5 per cent. nickel steel, where fracture has occurred between the cams caused by torsional vibration under excessive speed conditions: Fig. 25d shows the failure of a case-hardened " spring-drive " shaft in nickel-chromium steel, starting at the bottom of the serrations and attributed to shock loading caused by back-firing after closing the throttle.

10. FLEXIBLE TRANSMISSION COUPLINGS AND ENGINE MOUNTINGS.

Much useful development may be expected in the future in the direction of flexible transmission couplings between engine and airscrew, whereby the airscrew would be virtually isolated from engine vibrations, also, in flexible engine mountings to isolate the aircraft structure from these vibrations. For this purpose, the use of bonded rubber—to the purely technical aspects of which material, some reference has been previously made in Part III, Section C—appears to be especially suitable.

With regard to crankshaft dampers of this material, much has been accomplished in the automobile field and applications to aircraft are, as yet, only in the experimental stage as far as this country is concerned, although being pursued. It has been previously shown that, by the use of suitable rubber mixtures, a desired natural frequency of the damper may be obtained; for example, in the case of a crankshaft having a natural frequency of 15,000 cycles per minute, the damper rubber unit may be tuned to a frequency of $\frac{2}{3}$ of that figure, *i.e.*, 10,000 in order to obtain the maximum damping. A number of types are in course of development in which the rubber may be chiefly in compression or shear, or a combination of both; the metal separating plates are arranged horizontally, vertically or spirally to suit the needs of the particular design. The design aspect is most interesting but the purpose of the present note is merely to draw attention to the fact that much has already been accomplished in this field and future applications for aircraft purposes appear to be promising.

Essentially the same principles are used in the design of engine mountings as in shaft dampers. Whereas flexible engine couplings of this type have not,

as far as is known, yet been fitted to production engines in this country, engine mountings, both for radial and in-line engines, already find a limited use. Fig. 26 illustrates some engine mountings which have been developed. It appears that the development of bonded rubber has great potential uses and constitutes a valuable addition to aircraft materials of construction.

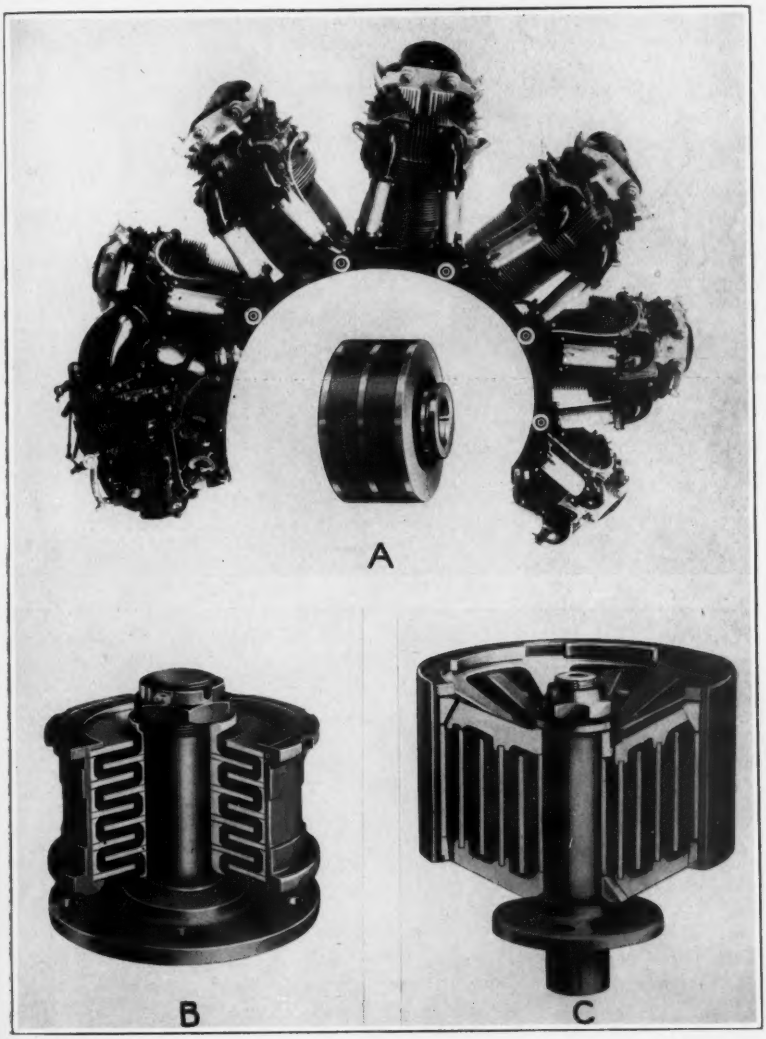


FIG. 26.

Engine mountings employing bonded rubber.

A. A mounting and its application to a radial engine.

B. Mounting for in-line engine: Rubber partly in compression, partly in shear.

C. Another type for in-line engine: Rubber in shear.

The problems encountered in aero-engines are indeed exhaustive but perhaps sufficient mention has been made to indicate that, in the search for still better materials of construction, there remains opportunities for much future research in ferrous and non-ferrous metallurgy. The improvements suggested will contribute to the production of engines up to 1,000 h.p., having better weight-power ratios than at present, while engines of 2,000 h.p. upwards could be developed still maintaining present weight-power ratios.

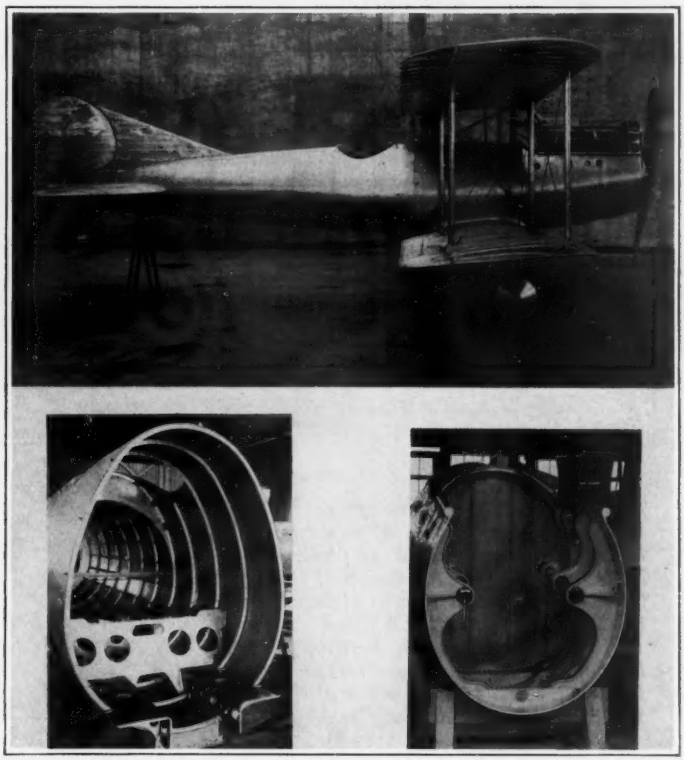
B. The Airframe.

1. The Development of the All-Metal Aircraft in Light Alloy.

The most remarkable changes that have taken place, during the last twenty-five years, in the airframe, although resulting chiefly from changing aeronautical requirements, have been greatly assisted by the improved materials of construction that have been made available; the design and materials aspects are so interwoven that, for the present purpose, they must be considered together. In designing the earlier types of aircraft, the main requirement was the provision of the necessary area of wing and control surface supported on a structure adequate to carry merely the aerodynamic lift, whereas, the modern structure has to combine a certain specified external form, having a very smooth surface, with sufficient strength to resist aerobatic loading, *e.g.*, pull-out from a power dive together with sufficient stiffness to obviate aerodynamic instability (flutter, reversal of aileron control). For many years wood, covered by fabric, formed the principal material of construction and in many ways it was and still is a satisfactory material. Wood is easily worked and the strength characteristics of selected timber are generally very reliable; it is not subject to corrosion and, in temperate climates, shrinkage may not be an important factor; its low shear modulus, however, is a drawback in its use as a stressed covering. It was the shortage of high grade timber at the end of the Great War that was largely responsible for the change to metal construction, where the development has been limited to the use of steel or light alloy for all main structural components. The Short "Silver Streak," illustrated in Fig. 27, is believed to be the first all-metal plane, including covering, produced in this country; constructed in 1919, it was exhibited publicly in 1920. The fuselage was of monocoque form built entirely of duralumin sheet with continuous angle frames and intercostal stringers of triangular section; the planes were also covered with duralumin sheet; the spars being round steel tubes and the ribs built up of duralumin angles on the lattice girder principle. The new "Empire" boat is a straight development from the "Silver Streak"; the fuselage construction of the latter is shown in Fig. 27a and possesses much historical interest as the design of the purely monocoque structure has really undergone very little essential change during the intervening years, an important improvement being the tubular stiffeners very recently introduced by the Royal Aircraft Establishment. The same year, 1919, saw the first all-metal construction in steel produced in this country, the rear fuselage of which was also of monocoque construction; in this machine, however, the fuselage and wing coverings were *not* of metal.

The relative merits of steel and light alloys involve a consideration of the different *forms* of the desired structure. In a biplane, one might prefer all steel construction and it is doubtful whether there would be any advantage gained in weight or ease of fabrication by the use of light alloy; in fact, any such advantage would largely depend on the experience and production facilities of the constructor concerned. Careful design has made possible the use of thin high tensile steel strip in which very high stresses may be developed, while steel spars and other structural members lend themselves very readily to mass production methods. Before leaving the aspects of primary strength and stiffness, it may be recalled that in comparing beams of similar cross-sections, having the same *strength* in bending but made of two different materials, the ratio of the stiffnesses is $(E_2/E_1)\,(f_1/f_2)^{4/3}$ while that of the weights is $(w_2/w_1)\,(f_1/f_2)^{2/3}$, where

E_1 and E_2, f_1 and f_2, w_1 and w_2, are the elasticities, strengths and densities, respectively, of the two materials. Now, very roughly, E, f and w are in the same ratio for all structural materials and, hence, in similar forms of structure, *the lighter material gives a lighter and stiffer structure.* Thus, it would have been a retrograde step to replace solid wooden spars by solid metal ones and the advantage of metal could only be realised by the use of very thin-walled construction. But such construction at once introduced the problem of secondary failure by instability under compression and shear at stresses much lower than the maximum the material itself can safely withstand. The liability to instability



Fuselage construction. *Engine mounting.*

FIG. 27.

The "Silver Streak" of 1919.
All-metal construction of light alloy.

can be reduced by local stiffening or curvature of the plate; curvature is appropriate when the stress is compressive but, in shear, special stiffening is necessary. To meet these needs, a most intricate system of spar sections was developed[56] and steel spars of this type enable full advantage to be taken of the intrinsic strength of the materials (45-50 ton steel strip was first used, later, as high as 75-85 ton alloy steels were developed); the problem of local instability has, how-

[56] "The Case for Metal Construction." J. D. North, "Flight," October 26th, 1922.

ever, never been entirely overcome and still receives much research attention. The evolution which has occurred through changes in the materials used for skeleton structures is illustrated by some of the details shown in Fig. 28. *A* shows a common form of spindled spruce spar of I section. The change over to the use of thin strip steel introduced some complicated designs of the general form shown in *B*; with this form, it is necessary to maintain a curvature in the flange of not more than 30 thicknesses in order to ensure stability. *M* shows a typical biplane spar section in duralumin. The use of rolled sections in light alloy permitted a reversion to the plain I section, as shown in *C*.

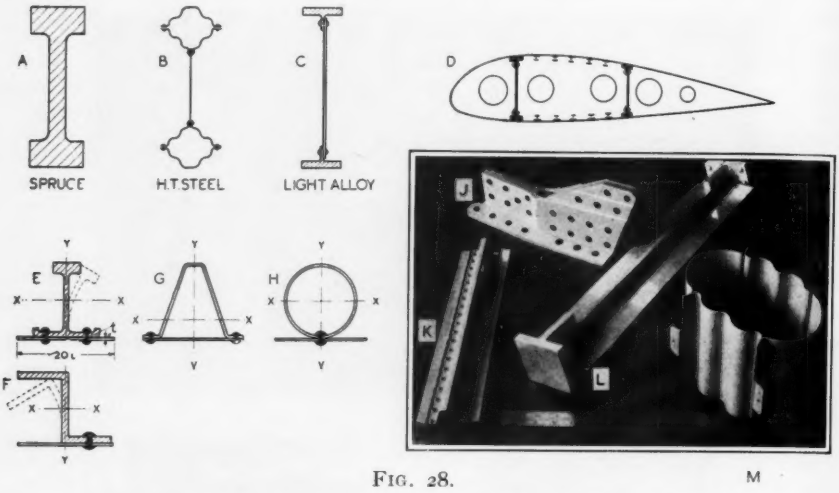


FIG. 28.

A, B, C. Illustrating development of wing spar sections.
D. Typical wing section of monoplane.
E. Stringer of very efficient form.
F. Common, but poor, design of stringer.
G. Asymmetrical design of stringer.
H. Tubular stringer (R.A.E.).
J. Stainless steel forging for attaching wing to hull of flying boat.
K. Typical closed stringer section for land plane.
L. Front or rear spar section of wing.
M. Typical duralumin spar section for biplane.

The problem of the spar having thus been met to a satisfactory extent, the next stage was the abolition of fabric as a covering; in service it suffered from many disadvantages and its replacement by thin sheet metal was a logical development. But very thin sheet of the lightest metals available weighed considerably more than the fabric covering it replaced and hence it was necessary to make the sheet metal take part of the load. As a first step, the cross-bracing wires between the lattice points of the basic metal framework were omitted and the metal panels used to transmit the shear loads, but this was soon followed by also imposing some of the direct loading, tension or compression, on the panels. Intrinsic lightness was still a paramount advantage, so that the light alloys began definitely to displace steel in skin-stressed structures. This change was *greatly* accelerated by the gradual supersession of the thin-winged biplane by the thick-winged monoplane, with the increase in wing loadings from 15 to 25-30lb./ft.^{2}. In a thin wing, the torsion load has to be resisted mainly by differential bending of the

front and back spars; in a thick wing, it is possible to use a box form of construction to carry the torque. Nevertheless, since on the wing the bending load is much the most serious, the spar form of construction has much to recommend it, and it remains in common use.

In present practice, the metal covering of the fuselage is usually required to carry all the shear loads and part of the direct loads, whilst in the wings, the sheet metal has often to transmit the shear load due to wing drag and may also be required to carry part or all of the shear due to torsion. Except in the multi-spar form of construction, however, it is seldom practicable to design a *thin* wing-covering to carry any appreciable part of the direct loads.

The use of thin sheet metal in compression or in shear raises problems of stability similar to those that arose in connection with the built-up metal spar; but in this case, except perhaps by the use of corrugated sheet, the liability to fail by buckling cannot be entirely avoided. The majority of aircraft fuselages as now constructed fail, under test, by some form of instability in compression or shear and the attention of the designer is largely directed to this type of failure. Now the stress which will cause buckling in the sheet is in general proportional to the elastic modulus of the material, to the square of its thickness and inversely to the square of its minimum free width. Thus, if the superficial dimensions and the weight of the structure are fixed, the buckling stress is proportional to E/w^2, so that, assuming E to be roughly proportional to w for all materials, the lighter material is again the better. The buckling stress can also be increased by reducing the free width of the sheet metal panels, and this can be effected by sub-dividing the longeron members into a large number of stringers of fairly small cross-section riveted to the metal sheet. At the same time transverse rings are necessary both to maintain the form of the fuselage and to limit the free length of the stringers themselves, whilst certain special transverse frames may be required to transmit concentrated loads. In this type of reinforced pure monocoque the panels between stringers will normally buckle at a fairly low load, but failure in bending will not occur until one or more of the stringers also buckles in compression. Failure in torsion may be determined by tearing of the sheet or by collapse of the stringers or rings under the bending loads imposed by the tension diagonal stresses in the buckled sheet; but usually the strength in bending is the determining factor. It will thus be seen that in the monocoque fuselage, no real advantage can be taken of any improvement of strength of the material above the buckling stress; what is required is a material having a higher E and/or a lower density. In the wing, on the other hand, whether a spar or a box form of construction is used, instability can usually be avoided, and in that case full advantage can be taken of any increase in the intrinsic strength of the material. It is important to notice, however, that a high strength may be rendered useless by a low 0.1 per cent. proof stress, since aircraft are usually required to carry three-quarters of the full factored load without permanent deformation. Ultimate strength is really the criterion for complete collapse and is normally more than $1\frac{1}{3}$ times the proof stress.

Returning to the fuselage it is necessary to remark that it is never possible to maintain the true monocoque form over the whole length. Openings have to be cut in the metal covering for cockpits, doors, windows and bomb holes. The distributed loads that would otherwise be transmitted across these openings have then to be collected and carried round the edges. A similar problem concerns the provision that must sometimes be made for detachment of one portion of the aircraft from another (*e.g.*, rear end of fuselage from wing section); this again entails the collection of distributed load into one or two booms or longerons. These larger members are often of such section that instability is not in question and in this case high strength is definitely advantageous. On the other hand, the load in such cases is usually purely tension or compression so that increase of strength is worthless if it is accompanied by a comparable increase in density.

To sum up from the point of view of the structure, the chief need is for lighter materials, of which the intrinsic strength and stiffness may be less, provided neither is reduced in much greater ratio than the density. Increase of strength or increase in 0.1 per cent. proof stress, whichever is the determining factor, is worth having, providing the density is not increased; but even a small increase in density may more than offset the advantage of a slight increase in strength.

The foregoing discussion has been made on perfectly general lines; to illustrate the arguments, Table VII has been prepared, choosing the following materials. The steels are those normally employed for metal construction of that type; the spar strip is the 65 ton proof, 1½ per cent. Mn. steel, the covering being the 45-ton proof, high chromium stainless steel. The aluminium alloys chosen are those used in production aircraft, the extruded spar section material being of the improved duralumin type, the covering being a normal duralumin in the "clad" condition. Aircraft construction in magnesium alloys is in the experimental stage only; the alloys mentioned in Table VII are standard commercial production materials. Ordinary spruce is inserted for comparison purposes, while the plywood referred to is in use at the present time in the stabilised stress-skin construction of production aircraft. The comparison brings out the advantage possessed by aluminium alloys over steel, while the figures relating to magnesium alloys indicate the possibilities of those alloys if certain disadvantages, such as corrodibility, could be overcome. The possibilities of the use of the improved woods are also apparent.

TABLE VII.

RELATIVE CHARACTERISTICS OF STRUCTURAL MATERIALS.

		0.1% P.S. (f) tons/in²	E lb./in²×10⁻⁶	Sp. Grav. (w)	Ratio f : E : w
A. Steel	1. Strip for Spars	65	29.5	7.8	1 : 0.45 : 0.12
	2. Strip for Coverings	45	28	7.8	1 : 0.62 : 0.17
B. Al. Alloy	1. Extruded Section for Spars	21	10	2.75	1 : 0.48 : 0.13
	2. "Clad" Sheet for Coverings	13½	10	2.75	1 : 0.74 : 0.2
C. Mg. Alloy	1. Extruded Section for Spars	10	6.5	1.82	1 : 0.65 : 0.18
	2. Sheet for Coverings	7	6.5	1.82	1 : 0.93 : 0.26
D. Spruce	As formerly used for Spars	2 (equiv.)	1.5	0.45	1 : 0.75 : 0.23
E. Plywood (Impregnated & Compressed)	As used for Coverings	5	2.8	0.96	1 : 0.56 : 0.19

Material.	Beams of geometrically similar Cross Sections, similarly stressed (to f) Relative Stiffness. $(E_2/E_1)\,(f_1/f_2)^{4/3}$	Relative Weight $(w_2/w_1)\,(f_1/f_2)^{2/3}$	Material.	Sheets, of same superficial dimensions and weight, failing by Instability. Relative Buckling Stress E/w^2
Steel (A1)	1	1	Steel (A2)	1
Al. Alloy (B1)	1.53	0.75	Al. Alloy (B2)	2.9
Mg. Alloy (C1)	2.67	0.81	Mg. Alloy (C2)	4.3
Spruce (D)	5.27	0.59	Plywood (E)	7.2

The important development of the production[57] of extruded sections in light alloy has largely led to the replacement of rolled and drawn sections. Some typical examples and applications have been reproduced in Fig. 16, while Fig. 28l is a photograph of an actual section. The latter illustrates the use, in a skin-stressed wing of modern design, of extruded spar flanges of high tensile aluminium alloy (RR56) with a web of duralumin sheet. At the root, it may be found economical to introduce steel reinforcement in order to reduce the size of the attachment; the approximate identity of the ratio of proof stress to Young's

[57] "Manufacture of High-Strength Light Alloy Extrusions and their Use in Aircraft." R. Worsdale, "Metallurgia," Feb. and March, 1938.

modulus for steel and light alloy enables the two materials thus to be built up economically to form a composite structure. The stainless steel forging, used to connect the wing to the hull of a flying boat, is shown in Fig. 28j; it is made of 16-20 per cent. Cr., 1-3 per cent. Ni. steel, having a minimum U.T.S. of 55 tons/in.^{2}. Fig. 28d shows the cross section of a typical monoplane wing in which use is made of extruded flanges, of light alloy, riveted to a flat plate web and extruded stringers also of light alloy; the skin is of sheet or " clad " duralumin. In order to develop the highest stress in the construction, the design of the stringers is of great importance. Their function is not only to stabilise the skin under compression and shear, but also to form part of a composite beam or strut of which about 20 thicknesses (the actual figure varies with skin thickness and stress) of the skin, together with the stringer flange to which it is secured, form one flange; this area should be balanced by an equal area forming the free flange. The web should be as thin as possible, consistent with the requisite shear strength. Fig. 28e shows a stringer designed to develop the highest stress in the skin. The area of the free flange is equal to the area of the lower flange, plus about 20 thicknesses of the skin; the stringer is therefore symmetrical about the major and minor axes; in order to avoid premature secondary failure under compression, as illustrated, the free flange should have the maximum M.I. about the minor axis consistent with stability of the free edge of the flange. Fig. 28f illustrates a very common, but poor, design of stringer, because it is unsymmetrical about the minor axis, and premature secondary failure is very likely to occur. Fig. 28g is also a very common type of rolled stringer; in this case, the fault lies in the asymmetry about the major axis. Fig. 28h represents the tubular stringer designed by Gerard of the Royal Aircraft Establishment, which is very easy to fabricate and is ideal for use with thin skin; a simple method of overcoming difficulties in riveting this form has been developed; in flying boats, open stringers are still preferred for inspection reasons, but it is most probable that the advantages of the closed circular stringer will outweigh this consideration. Mention must also be made of the " Northrop " type of stiffener, for fuselage construction, in which the stiffener is a continuation of one of the overlapping skin plates, formed to a special shape.

Thus, the light alloy all-metal aircraft of to-day represents, as far as the materials are concerned, a steady development of the sheet alloys for stress-skin construction, but the outstanding feature is the use of extruded sections. With even the present facilities available for their production, no difficulty is seen in producing aircraft designs of an all-up weight of 70-80 tons; such an aeroplane would be about 180ft. span and a length of about 140ft. It is unlikely that single extrusions could be produced for the spars of such an aeroplane, but it would be relatively simple to build up a spar of two or more extrusions. In this most interesting period of development, the corrosion problem has been one of the most serious in connection with light alloy structures, but it has been largely solved by the introduction of the " clad " alloys, about 1930. Even with the " clad " materials, it is still considered desirable to use the anodic process for its additional protection and, for marine work, a final greasing with a lanoline solution is strongly recommended, while a cellulose finish with two coats of undercoating and two finishing coats provide a good additional protection; it is general practice to anodise all light alloys and paint with a cellulose varnish.

An aspect of extreme importance, not previously mentioned, is the ease of manufacture, and metals which are easily manipulated offer marked advantages. For this reason, those light alloys in which precipitation age-hardening takes place fairly quickly limits the time in which manipulation must be completed; whereas, in the improved alloys where precipitation takes place at some considerable temperature above atmospheric, this phase change can be delayed until produced by artificial heating conditions. The method of joining parts together is also most important. Skin-stressed construction is mostly riveted at the present time and any method by which the plates can be brought to the machine,

instead of riveting in place, offers an advantage. The same consideration will also apply to welded construction for which there is undoubtedly a great future. In one type of construction now being developed and employed, 90 per cent. of the riveting is done away from the final construction. Stringers are attached to the flat sheets, the whole is offered up to the frame, riveted in position and the stringer attachment completed.

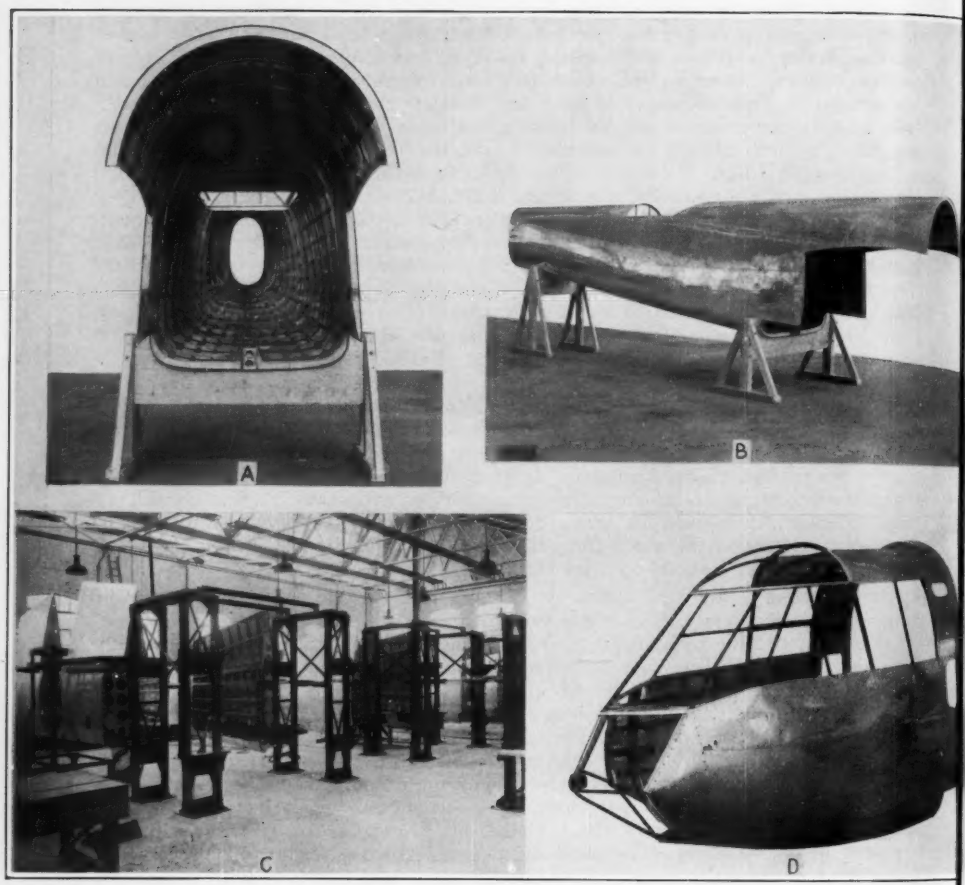


FIG. 29.

The Bristol "Blenheim."
A and B. Fuselage construction.
C. Wings; centre and outer sections on assembly jigs.
D. Nose-end of body.

This necessarily short survey of the development of metal stressed skin construction may be concluded with illustrations of some typical modern examples.

Fig. 29 a and b shows the fuselage construction of the Bristol "Blenheim" a modern high-performance aeroplane, constructed in light alloy except for a very few reinforcing stringers and angles at interruptions of surface. The keel, ribs,

and stringers are all of an alloy of the ordinary duralumin type, having a minimum U.T.S. of 24 tons/in.^{2}; the skin is of the same material in the " clad " condition. Fig. 29c shows the wing centre section (L.H. side of photograph) and the outer wings (R.H. side of photograph) on assembly jigs. The wing structure is of the stressed box construction, formed by two spars, ribs and skin. The spar flanges are made up of rolled sections of high tensile thin Ni.-Cr. steel strip, the stringers and stiffeners are drawn sections of light alloy strip of the " improved " duralumin type, the spar web of high tensile (28 tons/in.^{2} U.T.S.) " clad " duralumin; the wing ribs and skin are of the same material as the fuselage covering. The body nose-end, shown in Fig. 28d, is of similar construction. The principal features and the materials used in another plane, the Fairey " Battle," are shown in Fig. 8 and have been previously described in Part II, which also gives a description of the new " Empire " flying boat, the construction of which is illustrated in Figure 5.

FIG. 30.

Method of mounting engine on wooden wing construction.

2. CONSTRUCTION IN WOOD.

The technical characteristics of the natural and improved woods have been discussed in Part III, Section B, and it remains to refer to some applications in existing aircraft and development work that is in progress.

Probably the most interesting application of wooden construction to modern aircraft in this country is the " Albatross " machine, a photograph of which appears as Fig. 2, while some details of the construction are shown in Fig. 3 and have been briefly described in Part II. The stabilised fuselage construction, consisting of two sheets of three plywood separated by a layer of Balsa wood, is an excellent example of the strength and stiffness that can be obtained by combining the excellent properties of three plywood with new design. Similarly, the unorthodox wing construction takes the fullest advantages of the materials in their application to stressed skin construction suitable for a monoplane. On this point, it is stated that the wing is actually of thinner section than is usual in aircraft of this size, made possible by the " damping " nature of the materials used. The stability inherent in this wing construction is such that, under test, a stress nearly up to the ultimate compressive stress of the

laminated spruce skin is developed before failure occurs. That with such wooden construction, the mounting of the engine can be carried out in a simple and effective manner will be seen from Fig. 30; the mounting is of welded 30-ton 1½ per cent. Mn. steel tubes of round and square sections.

Much development work is in progress in the applications of reinforced timber for structural purposes; it will be recalled that this material consists essentially of laminations, with or without previous impregnation, and with or without fabric inserts, cemented together under pressure; the resulting specific gravity ranges from about 0.8 up to a limit of 1.4. These materials show to advantage under pure compression, the ultimate strengths being higher in proportion to specific gravity than that of aluminium and steel alloys; on proof stress they do not show up quite so well. Table VIII compares the average properties of a high grade material with one of the best wrought aluminium alloys available.

TABLE VIII.

GENERAL COMPARISON OF A HIGH-GRADE REINFORCED TIMBER AND A HIGH-TENSILE ALUMINIUM ALLOY.

	Reinforced* Timber.	Al. Alloy.
Specific Gravity (S.G.)	1.4	2.8
0.1% Proof Stress (P.S.) tons/in²	10.5	28
U.T.S. tons/in²	20	33
Young's Modulus (E) lb./in²×10⁻⁶	4	10
Shear Modulus (G) lb./in²×10⁻⁶	0.25	4
Ratios		
P.S./S.G.	7.5	10
U.T.S./S.G.	14.3	11.8
E./S.G.	2.9	3.6
G./S.G.	0.18	1.43

* Note.—These figures are conservative.

Thus, for purposes of monoplane wing construction, reinforced timber is well adapted to take bending loads either in the form of spar booms or skin covering, highly compressed timber being more suitable for the former. For the latter, on account of its greater bulk and inherent stability, timber of lower specific gravity is more suitable; if so used, the timber would serve as skin covering and shear bracing besides taking direct end load. But, as noted previously, the plywood skin, with separator, fulfils this purpose excellently. Reinforced timber shows up rather badly, when compared with *metal*, as regards the ratio of shear elasticity to specific gravity and this is important as affecting the torsional stiffness of a monoplane wing; adequate torsional stiffness is required to prevent reversal of aileron control and various types of flutter. For this reason, also the separated construction is such a valuable development. An interesting experimental development of the separated skin construction is the replacement of balsa wood by vulcanised expanded rubber, the latter being very light and free from the liability to moisture absorption, mould and fungus attack, possessed by the balsa wood and which makes necessary such careful sealing of joints and free surfaces; in an experimental wing section of this construction, a very good strength-weight ratio has been obtained under test; failure did not occur until a stress of approximately 4 tons/in.², reckoned only on the ply, was developed. Tests are also proceeding on the type of plywood which has an inner layer of duralumin; under very severe test conditions, the adhesion of the wood to the metal has proved to be very satisfactory.

It may occur that, in a wing section, the *depth* of the spar is fixed, but any economy in *width*, without sacrifice in strength, is an advantage. Some experimental results, which reveal the advantages of the improved woods in this respect, are of interest. Three hollow box spars, each 16ft. in length, were made up; the cross-sectional dimensions being as shown in Fig. 31. The booms of one spar were of ordinary spruce, those of the others being of different types of

impregnated and compressed laminated birch. Each spar was tested to destruction as a simply-supported beam over a span of 14ft. 6in. with a centrally-applied load. The load deflection curves obtained are reproduced in Fig. 31, while the inset table shows that marked economy of beam width and a small saving in spar weight can be obtained without any sacrifice in the total load-carrying capacity of the beam.

Laminated wooden construction lends itself very easily to strengthening by reinforcement at sections and ends subjected to heavy shearing or bearing forces; this can be achieved by fabric inserts introduced between the laminations. Where such loads are applied to timber through bolts, splitting is liable to occur; shearing tests of this type showed that laminated spruce, reinforced with fabric inserts, developed at failure, a load $1\frac{1}{2}$ times greater than that of plain laminated material and $6\frac{1}{2}$ times greater than that of ordinary spruce; some typical applications of fabric reinforcement for structural purposes are shown in Fig. 32. Another method, used in practice, of reinforcing tailplane spar joints, is by the use of plates of fabric-reinforced synthetic resin covered with plywood; these plates are glued on to the spar using a synthetic glue.

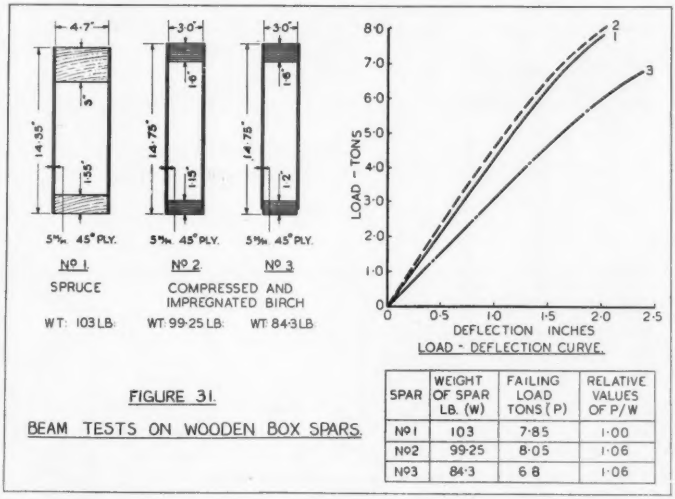


FIGURE 31.

BEAM TESTS ON WOODEN BOX SPARS.

SPAR	WEIGHT OF SPAR LB. (W)	FAILING LOAD TONS (P)	RELATIVE VALUES OF P/W
No1	103	7·85	1·00
No2	99·25	8·05	1·06
No3	84·3	6·8	1·06

FIG. 31.

Many other experimental developments are taking place in the use of compressed impregnated woods for structural purposes. As mentioned in Part III, Section D, dealing with wood, a spar may be produced having selected properties of strength and density, varying along its length. Experimental spars, of vacuum-impregnated and compressed wood, have been built up to 60 feet in length; such spars are not difficult to produce, neither is their actual cost of production uneconomic, but such production involves putting down, especially for the purpose, a considerable volume of rather expensive press plant. However, the further application of improved wooden construction to aircraft purposes appears to be most probable.

3. CONSTRUCTION IN PLASTIC MATERIALS.

The idea of aircraft structures entirely made of moulded plastic construction is most attractive and many references to the possibility occur both in technical literature and in fiction. The materials offer the advantages of extreme surface

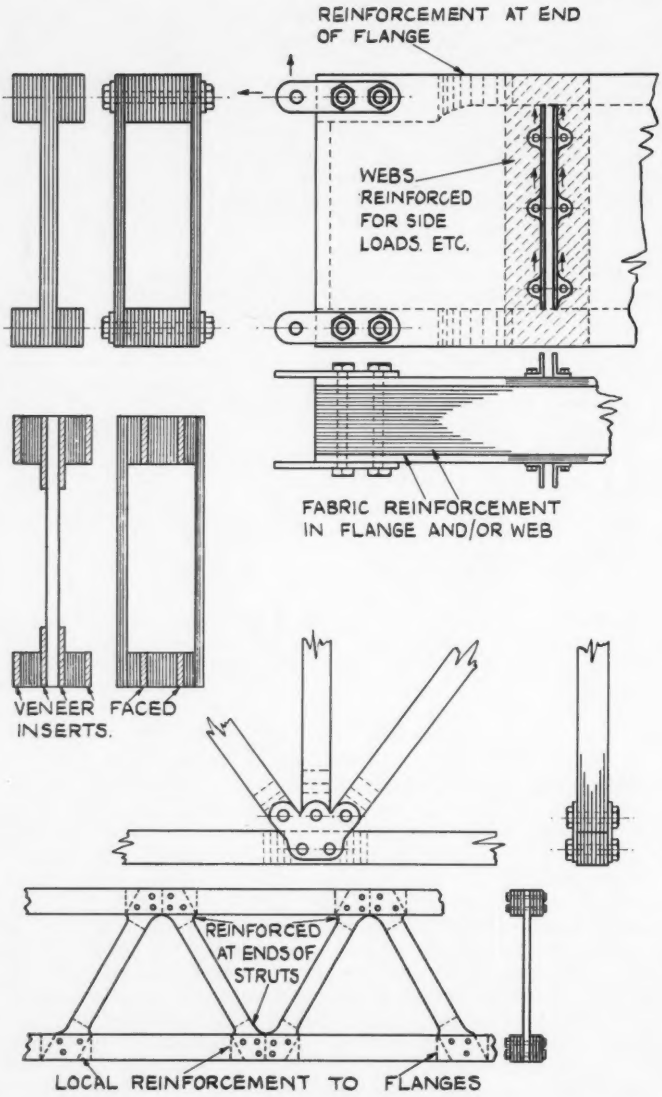

REINFORCEMENT AT END OF FLANGE
WEBS REINFORCED FOR SIDE LOADS, ETC.
FABRIC REINFORCEMENT IN FLANGE AND/OR WEB
VENEER INSERTS.
FACED
REINFORCED AT ENDS OF STRUTS
LOCAL REINFORCEMENT TO FLANGES

FIG. 32.

Some applications of compressed wood locally reinforced against shear.

smoothness, stability, low water absorption and ease of mass production. But, although a plastic non-stressed fuselage *covering* actually appeared as early as 1919, it is believed that no aeroplane made of plastic has yet been seen in flight nor has one even been constructed. From the structural point of view, a plastic material to be successfully applied should have a strength-weight ratio substantially equal to that of steel, light alloy or wood, based on tensile or compressive strength whichever is the lower; also, since deflections are so important in aircraft structures, the further criterion of elastic modulus weight ratio is also involved; shear strength characteristics may often be dealt with by suitable design. But it is merely foolish to dismiss from consideration the potentialities of plastic construction, as is so often done and, in this 1938 Wilbur Wright Lecture—which aims at presenting the present-day position—the omission of a reference to some most interesting development work that is being steadily carried out would be regarded as a very regrettable omission. Through the much appreciated collaboration of the inventor concerned, the inclusion of such a reference has been made possible. About ten months ago, a description[58] was published of a new type of wing primarily designed for construction in plastic materials. The prototype wing was built in wood and successfully emerged from its tests. At that time, no decision had been taken regarding the choice of plastic material to be utilised for the purpose. The choice has now fallen on a special material made from a cellulose fluff impregnated with a phenolic resin which can be moulded into a required form under a pressure of 2 tons/in.^{2} at 150°C.; passing reference to this material was made in the section on Plastics in which the results of tests made on samples cut from moulded panels have been quoted. Comparing these data with those of the high grade reinforced timber (U.T.S. 20 tons/in.^{2}) and the best wrought aluminium alloy available (U.T.S. 33 tons/in.^{2}), the comparison stated in Table IX emerges.

TABLE IX.

SPECIFIC PROPERTIES OF ALUMINIUM ALLOY, REINFORCED TIMBER AND PLASTIC MATERIAL.

Material.	Ratios. P. Stress / Sp.G.	U.T.S. / Sp.G.	E. / Sp.G.
Al. Alloy	10	11.8	3.6
Reinforced Timber	7.5	14.3	2.9
Plastic Material	4	6.4	1.4

Tests on struts, and on experimental mouldings of skin and typical components have been made and the experiences gained from these have been incorporated into improved design. Complete designs have now been prepared for a single-engined aeroplane, also, a two-engined plane, having all-up weights of 5,750lb. and 10,000lb., respectively. It is estimated that the times required for the production of the complete basic moulded panels from which these machines are assembled would be 82 hours and 135 hours, respectively; it is stated that assembly of the finished panels is more rapid and less costly than construction by the present methods, since skilled and experienced labour is not required. The principal details of the proposed construction are shown, diagrammatically, in Fig. 33. The stiffening ribs, moulded integral with the wing or fuselage skin, are interesting features, also, the bulb-ended form of the three wing spars, and the stiffeners on the spar webs. On the important aspect of joining, metal inserts for bolts or screws are stated to be unnecessary as the material itself holds a screw quite satisfactorily.

The progress of this development of the aircraft of moulded material will be followed with the greatest interest; it may prove to be the forerunner of a

[58] "A New Wing." "The Aeroplane," July 21st, 1937.

revolutionary step in aircraft design and in the use of a new material. That the skill and enterprise of the inventor and his associates will be rewarded with success is the hearty good wish of all.

C. The Airscrew.

Airscrew development has been controlled by three almost independent influences, *i.e.*, the normal search for improved materials, the changing demands

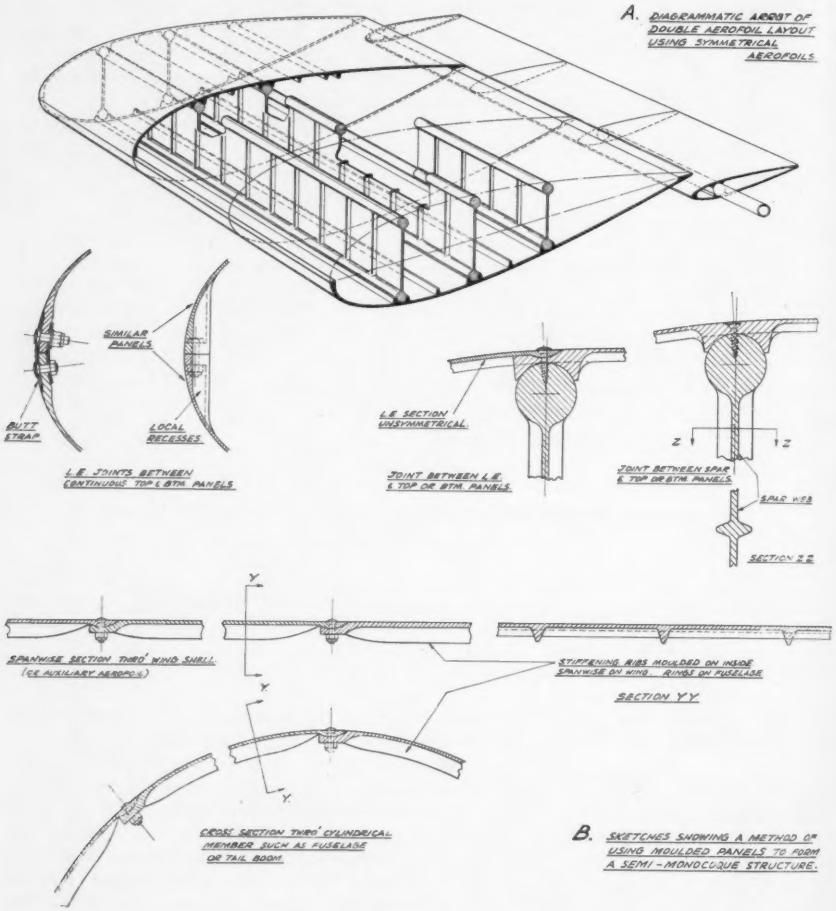

A. DIAGRAMMATIC ARRGT OF DOUBLE AEROFOIL LAYOUT USING SYMMETRICAL AEROFOILS
SIMILAR PANELS
BUTT STRAP
LOCAL RECESSES
L.E. JOINTS BETWEEN CONTINUOUS TOP & BTM. PANELS
L.E. SECTION UNSYMMETRICAL
JOINT BETWEEN L.E. & TOP OR BTM. PANELS.
JOINT BETWEEN SPAR & TOP OR BTM. PANELS.
SPAR WEB
SECTION Z Z
SPANWISE SECTION THRO' WING SHELL (OR AUXILIARY AEROFOIL)
STIFFENING RIBS MOULDED ON INSIDE SPANWISE ON WING RINGS ON FUSELAGE
SECTION Y Y
CROSS SECTION THRO' CYLINDRICAL MEMBER SUCH AS FUSELAGE OR TAIL BOOM
B. SKETCHES SHOWING A METHOD OF USING MOULDED PANELS TO FORM A SEMI-MONOCOQUE STRUCTURE.

Fig. 33.

Sketches showing details of proposed aircraft of moulded plastic construction.

imposed by alterations in aeronautical requirements as such and apart altogether from the consideration of the materials available, and the steady increase in engine powers. At the present time, particularly, the position regarding the most suitable materials for airscrews is in an extremely interesting state of uncertainty and change. Twenty years ago, airscrews were almost universally constructed of timber, chiefly of laminated mahogany or walnut in this country. Ten years ago, probably 90 per cent. were still of wood, a few were of steel and aluminium

alloy. To-day, probably 50 per cent. are of wood, 45 per cent. of aluminium alloy, the remaining 5 per cent. of compressed and laminated wood, steel, or magnesium alloy.

The early wooden screws were extremely reliable, free from fatigue troubles, cheap and easy to construct; nevertheless, they suffered from several disadvantages. In particular, they were subject to distortion owing to moisture absorption, were easily damaged by stones, spray, etc., and were difficult to repair. Consequently, the possibility of using metal became a matter of concern and, during the approximate period of 1917-22, two main attempts were made in this direction. Hollow steel blades, made of thin sheet riveted and welded together, were built, but were unsuccessful owing to fatigue troubles. The first successful departure from wood was the use of a thin flexible blade of aluminium alloy to suit a design in which advantage was taken of the centrifugal forces to offset stresses due to the imposed bending moments. But with the increase in engine power, a modification of the essential principle of this type became necessary and the blade thickness had to be increased. Great care had to be employed in the disposition of the holes through the blade, which carried the bolts of the standard wooden airscrew hub, in order to avoid fatigue cracking, but this and similar problems were successfully solved. Then came the most profound influence of all, the advent of the variable pitch screw, made necessary for various aeronautical reasons which are well known. Owing to the liability of natural wood to change its dimensions with varying moisture content, the problem of holding blades securely at the root under big centrifugal loads coupled with vibration was too difficult; further difficulties would be introduced by the relatively low shear strength of wood. Thus was rendered an unusually heavy blow, for a new and most effective method of protecting the surface of wooden screws had been devised which would probably have put such screws right on top again. But, in the meantime, aluminium alloy forgings had been so greatly improved, both in strength and grain flow disposition, that this metal became supreme for variable pitch airscrew blades, and, in fact, remains so at the present time. But the advantages of the much lighter magnesium alloys had not been overlooked and great advances have been made, in recent years, aimed at the improvement of the physical properties of these alloys and the manufacturing technique of forgings. It is true that magnesium alloys suffer from serious disadvantages, such as corrodibility, notch sensitivity and relatively low fatigue resistance, but much success has been attained in overcoming or alleviating these troubles. It is estimated that about 100 modern magnesium screws are flying or have flown in this country; screws of this material are now in active commercial production and have an assured future. Comparatively recently, a powerful new entrant has arisen in this most competitive field, *i.e.*, the screw made of laminated, impregnated and compressed wood. By the use of one of several most ingenious manufacturing techniques, airscrew blades are now made having properties in various parts designed to suit the imposed stress systems; the lightness and other advantages of ordinary wood may be approached in the blade while the necessary increased resistance to shear and tension at the root is attained. This type of screw has also emerged successfully from the experimental and development stage and is in commercial production and has an assured future. This type has successfully emerged from all bench tests; at the present time, it is estimated that between 30 and 40 screws (say, 100 blades) of a compressed wood are in flight in this country, a maximum flying experience of about 1,000 hours. There remains one other general type to mention, the reinforced synthetic resin. Experimental development in this field commenced certainly as early as 1917 and, as improvement in reinforced plastics developed, the airscrew application was also followed up. Such development is in progress to-day, with interesting results, but to describe this as having gone beyond the experimental stage would unfairly represent the present position; the future possibilities of this construction are still obscure; this type of screw is not yet in commercial production.

To sum up the broad position as far as this country is concerned, variable pitch propellers are practically all metal with a small percentage of the compressed wood root type, while fixed pitch propellers are mostly of wood. Certain features of each type of material may now be briefly discussed.

1. Wooden Propellers.

The method of construction is well known. The principal development has been in manufacturing technique, the biggest improvement probably being the change over from the use of the original hot hide glue to casein cement (about 1925); synthetic glues are also used and are very good, their advantages and disadvantages have been discussed in a previous section. The methods of protection against moisture, absorption and erosion are important. Fabric covering with varnish finishes, also metal sheathing of the leading edge are successfully employed, but, for marine purposes, the latter has never been entirely successful, fabric or synthetic coverings proving superior. The " Schwarz " process of protection is an outstanding development. The airscrew surface is hermetically sealed in a very hard cellulose acetate mantle giving protection against moisture, erosion, and corrosion; under this, and covering the whole of the blade and boss, is a layer of either fabric or metal gauze, while the leading edge is further reinforced by a narrow brass sheath sweated to a strip of wire gauze. The outer cellulose sheathing, applied in a soft and plastic condition, is firmly bonded to the wood during the final process of hardening under pressure and temperature. A diagram showing a cross section of such a protected blade has been published.[59]

2. Aluminium Alloy Propellers.

The material universally used in this country is an alloy of the duralumin type. The two materials developed for this purpose have the following composition and approximate mechanical properties.

Ref.	Cu.	Ni.	Mg.	Si.	Fe.	Mn.	Al.	0.1% proof	U.T.S.	Elong. %
A	3.5/4.5	—	0.5/0.7	—	0.75 max.	0.4/0.7	Remdr.	13.5	22.8	15
B	1.5/3.0	0.5/1.5	0.4/1.0	1.0 max.	0.8/1.4	—	,,	20	27	10

All the screws in present commercial production are to specification A, as importance is attached to the greater ductility obtained, while it is considered that the higher strength of B could only be usefully employed if associated with a higher value of Young's modulus (E). However, research and production experiment are being devoted to the improvement and use of higher strength alloys. Anodic treatment is used for protection against corrosion; coupled with a regular wipe down with an oily rag, using thin lanoline or tung oil, satisfactory service of several years' duration has been obtained under severe conditions. Forced vibrations from the engine impose substantial additive stresses on the screw and the resulting liability to fatigue failure is ever present in metal propellers; although, in the extensive experience of a British firm of aircraft builders and operators, a root fatigue failure in a duralumin propeller has never been encountered, serious failures are reported in foreign literature. In this connection, it is most important to achieve a correct grain flow at those parts of a blade forging where transition curves and fairly sharp corners are rendered necessary by design requirements and induce stress concentration effects; special grain flow examinations are made at important points such as the root blade and in the boss. Fig. 34 is a typical example, taken from commercial production, showing almost continuous grain flow, of the required type, in a blade root flange. Duralumin propellers are being made in diameters ranging from 6ft. to 16ft., having weights from 70lb. to 600lb. and designed for engines of from 120 to 2,000 h.p.

[59] " Airscrew Development." H. C. Watts, Jour. Roy. Aero. Soc., July, 1936.

3. Steel Propellers.

Solid steel screws being out of consideration owing to their weight, the hollow type has received attention; both mild steel and chromium-molybdenum steels have been used. Liability to fatigue has been the outstanding difficulty, failures occurring either near the root sleeve or near the tip owing to resonant vibrations of the thin wall. In this country, steel screws withstood most successfully severe bench tests; directly they were tried in the air, they failed in less than 100 flying hours and their development has been abandoned, at least temporarily. In the U.S.A. steel screws are still employed to some extent, but the possibility of fatigue failure is ever present and stringent periodical tests are made to detect incipient cracks. The fitting of elastic engine couplings, together with improvements in the materials and production methods, might bring steel screws back into the picture for small and medium engine powers, but for the larger engines now in development, the fitting of steel screws appears to be most improbable.

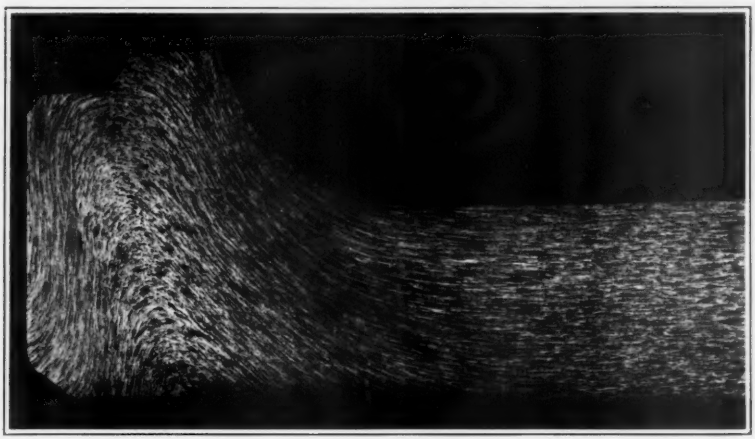


Fig. 34.
Grain flow in the blade root flange of a variable pitch airscrew (duralumin).

4. Magnesium Alloy Propellers.

The failures encountered with the earlier magnesium propellers were such that a prejudice grew up against their use which is still encountered in many quarters. Magnesium offers such great attraction because of its intrinsic lightness and specific tenacity, but these are offset by its marked corrodibility, notch sensitivity and forging difficulties. However, remarkable improvements have been made recently in forging technique, while various improved protection methods are now available; nevertheless, in this country at the present time, magnesium alloy screws are envisaged primarily for land machines in which corrosion is not assessed as such a serious problem. It is a fact that, in the first propellers, the change over from duralumin to magnesium was made without any alteration in design, a misguided attempt to take the maximum advantage of the lower specific gravity of the latter material; when the weight saving was reduced to 25 per cent. or less, greater success was obtained. But within the hub, failures still occurred, due to fatigue and fretting and, although the expedient of surface rolling gave some improvement, complete immunity was not achieved until the practice was adopted of inserting a synthetic fabric reinforced sleeve between the screw blade and the hub, allied with the use of an improved form of screw thread which

considerably reduced the stress concentration effect. These experiences were principally obtained abroad, but the lessons learned have been fully utilised in this country in present production. With regard to methods of protection against corrosion, the chromate treatment is partially effective, but the film is easily damaged and cannot be maintained along the leading edge, so that rubbing down with lanoline after each flight is necessary; it seems probable that the greatest improvement in corrosion resistance will ultimately be obtained by a more suitable balance of the chemical constituents of the metal itself and research in this field is already showing promise. Reverting to coverings, it may be mentioned that two other methods are in experimental development, the use of a celluloid-like covering which hermetically seals the blade against water penetration and also affords protection against erosion, also rubber coverings, one method being of dipping the blade in a latex solution. Magnesium suffers from low surface adhesion properties and it is difficult to get a satisfactory bond with a covering; with regard to synthetic rubber, however, a satisfactory process has now been established.

Airscrew forgings of magnesium alloy are made to a specification in which the *maximum* contents only are stated as follows:—Al. 11 per cent., Zn. 2 per cent., Mn. 1 per cent.; as a result, there is a wide scope for the manufacturer, which has been and is being fully utilised. Two years ago, specimens cut from an airscrew forging gave:—0.1 per cent. proof stress 10 tons/inch^2, ultimate tensile 17-18 tons/inch^2, elongation 6 per cent., Wohler fatigue limit $\pm$8.6 tons/inch^2. More recently, samples cut from six positions in a screw forging gave:—0.1 per cent. proof stress 11-13.5, ultimate tensile strength 18.7-21.5 tons/inch^2, elongation 6-8 per cent., Wohler fatigue limit of $\pm$9 tons/inch^2.

5. Airscrews Containing Laminated, Impregnated and Compressed Woods.

In no other material for airscrew purposes has there been such rapid development as in the use of what might almost be called the " synthetic " woods. The general nature, methods of manufacture, and some typical mechanical test data have been previously described and stated in Part III, Section B; the present discussion will be confined entirely to the airscrew aspect.

These materials are produced to combine the good properties of natural wood, *i.e.*, low specific gravity and high specific tenacity, marked damping characteristics, relative freedom from fatigue and notch sensitivity, with the improved qualities required in the root of a variable pitch screw blade. An airscrew blade is a component in which the stress requirements vary from point to point along the blade. At the propeller tip, good notch resistance and low specific gravity are essential requirements; at the centre of the blade, good bending and tensile strengths are desirable; at the root, tensile strength combined with resistance to shear and shock are imperative. Such a combination logically demands a built-up construction; the improved wooden construction goes a long way towards meeting these demands without the undesirable complications of riveted or similar joints. The type which is in commercial production in this country consists essentially of a blade of a light laminated wood construction, scarfed, by an interrupted series of long spliced joints, to a root block of laminated, resin-impregnated and compressed hard woods, which may also be interleaved with fabric; casein or synthetic glues are used for joining purposes. For example, where spruce is used for the blade, and compressed and impregnated birch or beech for the root, the densities, of blade and root, are 30lb./ft.^{3} and 80lb./ft.^{3} respectively. In general, the tensile strength of the wood goes up roughly in proportion to the degree of compression, as shown in Fig. 18, but an increase in shearing strength of four to five times may be obtained. Some data, obtained from very recent tests, made on the material of an airscrew root, may be quoted to exemplify these points. The tensile strength, along the grain, was 40,000lb./inch^2, about 2½ times that of the uncompressed wood; the cross grain tensile strength was 2,500lb./inch^2; end grain compressive strength, 26,000lb./inch; shearing strength along grain,

7,000lb./inch², a value four to five times that of the uncompressed wood. A steel socket is screwed to the root of the blade and a self-hardening and expanding filling compound is injected, under very high pressure, between the root and the socket. For protection purposes, the blade is covered and reinforced using the cellulose acetate and sheathing method previously described in the sub-section dealing with wooden propellers. The largest propeller of this type in flight is a three-bladed propeller of 12ft. diameter; it replaced a duralumin propeller of 13ft. diameter; an airscrew of 16ft. diameter is in course of manufacture, designed for use with a 2,000 h.p. engine.

A note on the amount of wastage involved in the process may be of interest. The veneers for compressed wood are, naturally, most carefully selected and only about 20 per cent. of the original tree finds its way into compressed wood of first quality with the result that rejections, during inspection, of compressed boards are negligible. The veneers not selected for high strength compressed wood find their way into lower qualities and eventually into ordinary plywood. There is thus very little reject on the whole process.

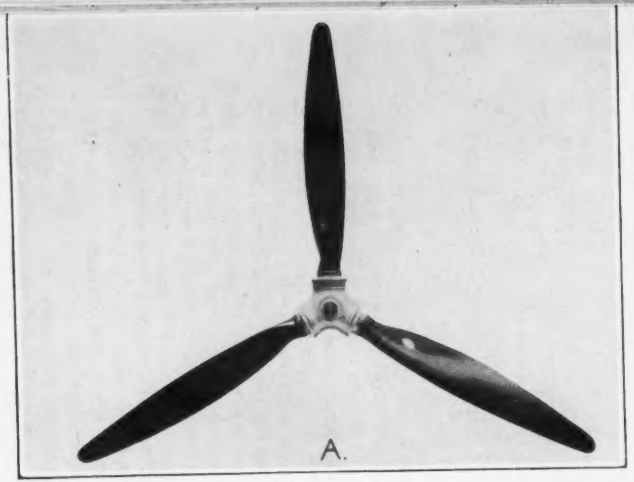
In addition to the process described above, it may be noted that other methods of construction of airscrews from compressed woods are in experimental development in this country.

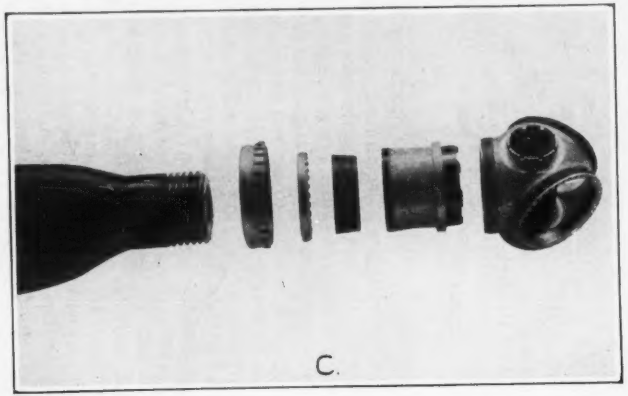
Metal airscrews are very similar in appearance and Fig. 35a will serve as a typical modern production; it illustrates a screw of diameter 12ft. 8in. used with an engine of 1,010 h.p.; the blade material is magnesium alloy, each blade weighs 58.5lb., the weight of the complete screw being 344lb. Fig. 35b shows, in the course of manufacture, one of the improved wood screws previously described; the interrupted junction between the root and the blade is clearly visible. Fig. 35c shows a dissembly of a magnesium blade root. One interesting feature is the coarse thread on the blade root, having different radii at the root and crown of the thread. The tapering bush is of laminated synthetic resin and provides the solution to the serious " fretting corrosion " troubles formerly encountered. It gives an extremely solid locking, to such an extent that a special loosening technique is required when the blade is removed or reset; this takes the form of forcing in grease at about 3,000lb./inch² pressure, which is sufficient to expand the hub and force a film of grease between the surfaces. Fig. 35d is a dissembly of the hub of an improved wood screw, showing the steel screwed sleeve attachment.

6. Airscrews of Reinforced Synthetic Resin.

The general types of reinforced resin materials and their properties have been discussed in the section on plastic materials. In the airscrew application, intrinsic advantages of these synthetics are marked resistance to corrosion, damping capacity and reasonably good fatigue properties; low values of elastic moduli (E and G) and a liability to deform at relatively low stresses are intrinsic disadvantages. The specific gravity is such that, owing to the need for substantial thickness to provide adequate stiffness, the actual weight of an airscrew blade in this material does not show much advantage when compared with the weights of blades of the light alloys. For economic reasons, its method of manufacture would appear to restrict it to production on a fairly large scale.

Attempts to develop airscrews of this type are not new; a patent was taken out as early as 1919 in the U.S.A.; controllable pitch screws of reinforced synthetics were also produced in that country much more recently. In this country, experimental development has mainly taken place in the direction of the production of improved materials and methods of construction. We have already seen in Table VI that, by the use of corded reinforcement, a tensile strength of as much as 69,400lb./inch² has, very recently, been obtained. The strength given by corded reinforcement has been skilfully utilised to give considerable shear strength at the blade root by causing the cords to follow the contours of the blade surface; in a test, a force of 180 tons was required to tear





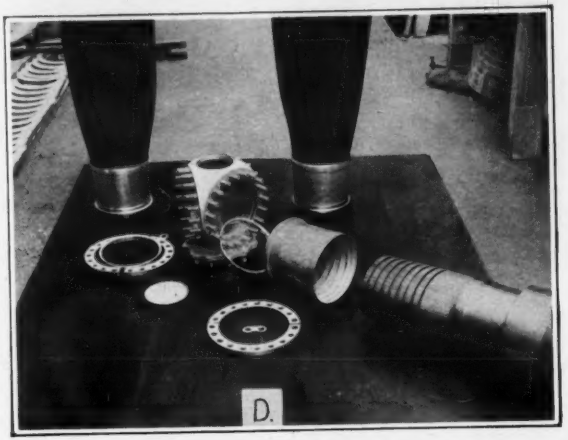


FIG. 35.

A. Magnesium airscrew, 1,010 h.p. engine, weight of each blade 58½lb., total 344lb.
B. Showing transition from block to blade in compressed wood construction.
C. Dissembly of magnesium blade, showing special anti-fretting bush.
D. Dissembly of bolt [illegible] special clamps.

off the root from the blade, a notable achievement; the estimated centrifugal force under running conditions is estimated at 28 tons. Perhaps the best example of recent experimental development is the *hollow* moulded blade. An experimental screw of this type is probably the largest moulding yet made in which continuous lengths of fabric in cord or sheet form have been used. The threads at the root end forming the flange are unbroken throughout the whole length of the blade except in so far as is necessitated by the gradually reducing cross section. At the root, these cords follow the surface contour in a similar manner to the grain flow in a well designed metal screw. The reinforced material gave a tensile strength of 35,000lb./inch^2. A core of fusible metal is accurately located in the centre of the blade round which the reinforced material is moulded and compressed; the core is subsequently removed by the use of a high frequency induction furnace and without causing damage to the plastic material; each blade was 78in. in length, forming a 13ft. 6in. diameter screw; a complete blade was made in eight hours. The weight of each blade is 52lb. before trimming, compared with 65lb. for the equivalent blade made of metal. It is stated that no manufacturing difficulties would be encountered in a blade of as much as 20ft. in diameter.

It should be emphasised that the developments referred to above are purely experimental. They are being carried out by a well-known firm of aircraft manufacturers, the results of whose marked enterprise and skill in this field will be followed with the very greatest interest.

Reverting to airscrews in commercial production, it is pertinent to enquire how similar airscrews of different materials actually compare on a weight basis. It is very difficult to obtain strictly comparable data as direct replacements in service are rare and the great variety of engine conditions may easily lead to misleading comparisons. But I am fortunate in being permitted to present the data given in Table X which relate to actual designs in the three types of construction for identical service.

TABLE X.

THREE-BLADED AIRSCREWS DESIGNED TO ABSORB 1,600 H.P. AT 2,750 ENGINE R.P.M. DESIGN SPEED, 250 M.P.H. AT 10,000 FT.

Blade Material	Gear Ratio	Diameter of Airscrew ft.	Blade Root Diameter ins.	Design Stress in Blade tons/in2	Centrifugal Load, tons	Weight of Hub, Shell lb.	Weight of Blade, lb.	Weight of Complete Airscrew Assembly, lb.
Magnesium Alloy	.500	12½	6.0	4.5	49.5	52	78	419
	.500	12½	5.5	6.0	40.6	47½	64	352
Aluminium Alloy	.500	12½	5.5	7.7	53.0	53	93	474
	.500	12½	4.7	11.0	49.5	44	87½	425
Laminated Wood with Compressed Root	.500	11¾	6.7	—	18.2	41¾	46*	275
	.444	12¾	6.6	—	20.0	41¾	57*	308

* Including steel sleeve at root.

Speculations regarding the future of airscrew materials would be unwise as so many factors are involved. It is certain that engines of 2,000 h.p. will be available fairly soon. Larger powers will, in general, mean larger diameters of airscrews, although not perhaps to the extent that was envisaged at one time; it now appears certain that the airscrew for the 2,000 h.p. engine will not have to be as large as 20ft. diameter. But it is certain that, owing to the large increase in weight associated with increase in diameter, the need for the lightest possible material will become urgent. Taking the previous estimate of present-day practice as 50 per cent. wooden screws, 45 per cent. of aluminium alloy, 5 per cent. of compressed wood, steel, or magnesium, then allowing for improvements that may be normally expected, while recognising reluctance to hasty change, it appears probably that, five years hence, airscrew practice may be

total 3440.
B. Showing transition from block to blade in compressed wood construction.
C. Disassembly of magnesium blade, showing special anti-fretting bush.

represented by 70 per cent. made of aluminium alloy, 20 per cent. of compressed wood, and 10 per cent. of magnesium alloy. In ten years' time, we may see a real fight for supremacy between metals and non-metals for airscrew purposes. Although guesses of this sort may be interesting, they nearly always prove to be wrong; nevertheless, it is clear that, with regard to the materials for airscrew construction, the chemist, metallurgist and engineer have all a rich, interesting and useful field for research and development.

D. The Landing Gear.

1. The Undercarriage.

The modern landing gear consists essentially of the retractable undercarriage and the retractable tail-wheel unit; for the present purpose, a consideration of the former is sufficient. Such a unit consists essentially, in addition to struts and similar members, valves and control box, link mechanisms, safety-devices, etc., of four principal components:—(1) The wheel and tyre, (2) the shock absorber, (3) the hydraulic retracting jack, and (4) the pump. The modern shock-absorber usually takes the form of an oleo-pneumatic telescopic separate member or may be incorporated within the internally sprung wheel; the hydraulic jacks operate the retraction gear (similar jacks being used for the actuation of tail-wheels, flaps, turrets, doors, etc.); the pump, which may be engine-driven, hand-operated, or driven by a separate electrically-operated unit, supplies oil to the jacks, at pressures up to 1,000lb./inch^2.

Such landing gear presents many interesting problems relating to the materials used, many of which problems, however, are common to some of the other essential aircraft parts already considered; it will be necessary, therefore, only to refer to some of the special problems encountered. For convenience, the tyre will be discussed separately.

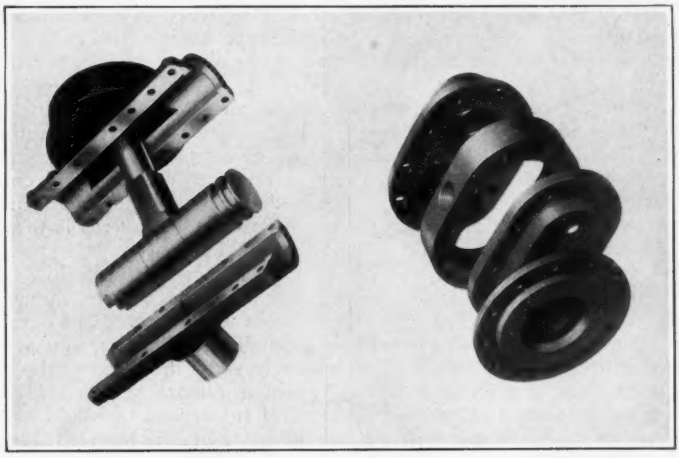
Magnesium alloys are used extensively both in the form of forgings (max. cont. Al. 11 per cent., Zn., 1½ per cent., Mn. 1 per cent.) and castings (max. cont. Al. 8½ per cent., Zn. 3½ per cent., Mn. ½ per cent.). The forged alloy is used chiefly for those components subjected to oil pressure, such as the bodies of hydraulic jacks, automatic cut-outs, etc., the porosity to which the cast material is liable renders it unsuitable for this purpose. Cast magnesium alloys are employed for wheels, bracing members for undercarriage legs, valves and pump parts; the ease with which these alloys are cast renders them very attractive for such components as oil reservoirs, a current example of which has a depth of 3in. to 4in., with a thickness of 0.1in. only. In other parts, also, the low modulus of the alloy is only a slight disadvantage as the desired stiffness can usually be obtained without difficulty. It is a curious fact that these alloys, both in the cast and forged conditions, are found to possess much better resistance to corrosion than the rolled material.

The cast magnesium alloys have been found to provide an extremely good bearing surface. For example, the sliding member of the internally-sprung landing wheel is a forging of a 65-ton nickel-chromium steel (Ni. 2¾-3½ per cent., Cr. ¾-1½ per cent.); these forgings were formerly bushed with phosphor bronze, but the bronze has now been dispensed with, direct bearing is made on to the cast magnesium alloy, and perfectly satisfactory performance is obtained. Fig. 36a shows this interesting combination.

An excellent example of a special use of an aluminium alloy arises in the outer casings of the engine-driven rotary pinion pump, in which the whole efficiency of the latter depends on the maintenance of a small and constant clearance of about 0.001in. Used at a hydraulic pressure of up to 1,000lb./in.^{2}, a marked rise of temperature occurs in service operation; if ordinary alloys were used for these casings, such a temperature rise would result in the immediate loss of the all-important clearance. The casings are, therefore, made of an aluminium alloy, containing Si. 10-13 per cent., Ni. 2½-3½ per cent., the coefficient of thermal

expansion of which approximates to that of steel: Fig. 36b shows some of these interesting components.

Steel tubing is extensively used in landing gear, usually made of a low alloy steel, containing manganese, and heat-treated to give a tensile strength not exceeding 45 tons/inch^2. The development of a *reliable* steel for tubes having a much higher tensile strength and, if possible, suitable for welding purposes, would be a valued contribution. The retractable landing gear of modern aircraft of 10,000lb. or more accounts for about *six per cent.* of the gross weight of the aircraft; if a satisfactory steel tubing were available having a tensile strength of, say, 95 tons/inch^2, it has been estimated that a weight saving of as much as 1½ per cent. of the gross weight of the aeroplane could be effected. Another required need is for a 120-ton machineable forging steel which, also, could be utilised to effect considerable weight saving. Practically no trouble is



A. B.

FIG. 36.

A. Internally-sprung landing wheel; high tensile steel forged tee-piece, sliding in magnesium alloy castings.

B. Casings of engine-driven rotary pump for hydraulic actuating gear, of low-expansion silicon-aluminium alloy castings.

encountered with coiled springs, but the present tendency is to replace springs altogether with the oleo-pneumatic type of shock absorber, for other reasons.

From the nature of their use, many landing gear parts are subjected to wear and corrosion. Moving steel parts are chromium plated and polished, giving protection against both wear and corrosion, such parts include telescopic members of shock absorbers, piston rods of hydraulic jacks, and the sliding member of the internally sprung wheel; stationary structural steel parts are cadmium plated. Components made of the magnesium alloys are protected by the black chromate finish previously referred to.

Synthetic resinous materials, reinforced with fabric, have recently been introduced, with success, as spacer rings for hydraulic jacks and effect some weight saving; these are also being experimented with as the material for the cylinders of the jacks; these synthetic materials also have a future use for sliding parts at present made in bronze.

The adoption of the engine-driven pump, involving a rise in temperature in the oil, has rendered unsatisfactory the use of materials previously used for the cups and gland rings of the hydraulic units. Ordinary rubber is quite useless as a substitute in contact with the hot oil, particularly with the oil of the " non-freeze " type which is now universally employed, and recourse has been made to the synthetic rubbers. Many have been tried without success, but a synthetic rubber has now been found which gives perfectly satisfactory performance. It may be pointed out that, in hydraulic jacks, friction must be reduced to a minimum and the use of the synthetic rubber has greatly helped to achieve this. Jacks employing this material have an efficiency of, approximately 90 per cent., as compared with 60 per cent. to 65 per cent. obtained with jacks using fabric type piston cups and gland rings.

2. The Wheel and Tyre.

Much development has taken place in the landing wheel in recent years. The wheels were originally of the tension wire spoke type having steel hubs and rims; such wheels were the practice as recently as eight or nine years ago, at which time the necessity for a rigid brake led to the built-up wheel made possible by the development of the centre and extruded rim of aluminium alloy. In fact, the advent of the rigid brake excluded the tension-spoke wheel from further consideration. Then, to reduce landing shocks by providing greater cushioning effect, high pressure tyres were replaced by those of low pressure having greater size, working pressures dropping from 60lb./inch^2 down to 25-35lb./inch^2; a further most important advantage gained by the use of low pressure tyres is the reduced contact pressure between tyre and ground, a valuable feature in heavy aircraft having to operate on the variety of types of surface encountered in different parts of the world. In order not to add to the overall size, the tyres were made of increasing cross-section, coupled with a decrease in wheel size. This development has now proceeded so far that difficulty is met with in obtaining sufficient space and operating area for the brake. The relatively small diameter of the wheel in relation to the tyre of a modern landing wheel is illustrated admirably in Fig. 15. The wheel is always of built-up or integral construction of light alloy, cast magnesium alloys of the 8½ per cent. Al., 3½ per cent. Zn., 1½ per cent. Mn., being employed. Extreme care has to be taken that these castings are free from micro-shrinkage and porosity defects and X-ray methods are usefully employed in this connection. It will be realised that the amount of energy to be absorbed during the landing and bringing to rest of an aeroplane is very great and the problems of the absorption, conduction and dissipation of heat, allied to the need for minimum weight, calls for the exercise of most careful design. Apart from accidents due to bad landings, failures in service are extremely rare but a few cases of fatigue in wheels have been encountered; it may be remarked that the standard static loading acceptance test (10:1 ratio) cannot give any indication of the fatigue resistance of the wheel. But it is certainly not intended to convey the impression that fatigue failure is at all likely under normal conditions; a large modern civil aircraft has just completed 1,200 landings without any signs of incipient failure in the wheels; training machines, however, receive very severe treatment, often in inexperienced hands, and reinforced landing gear equipment may be worth consideration. The hydraulically-operated brakes, lined with fabric asbestos, having a coefficient of friction of 0.4-0.45, present no special problems with regard to the materials used; the heat-dissipation problem is the all-important factor.

This brings one to the *tyre*. The tyre dimension is one of the first to be settled in aircraft design; when fitted, as usual, to a retractable carriage, it often affects the spar distances in the wing and other important features. The normal working load is based on a 33⅓ per cent. tyre deflection; vertical landing velocity, however, is the deciding factor, as in a bad landing, the downward acceleration

may be as high as 3g, in which case the wheel bumps practically down on to the rim. Hence the *cords* must be extremely strong and flexible; cord development is, perhaps, the most interesting aspect of the tyre as far as materials are concerned. The functions of the tyre are threefold:—The contained air is the cushion, the rubber supplies the flexible container, the strength is primarily given by the cords. Rubber exhibits marked strain hysteresis, but it may be pointed out that in a full deflection of the tyre the internal energy dissipated is quite insignificant in comparison with the elastic energy taken up by the tyre as a whole, which must be taken care of by the shock-absorber. No technical advantage would be gained in using synthetic rubber for the tyre, and, as the cost would thereby be very considerably increased, in this country, it is made from the natural product. The tread and side-walls of a modern aeroplane tyre are essentially similar to those of motor car tyres of the highest quality as far as composition is concerned; as described in Part III, Section C, the developments made in the rubber mainly relate to improvements in compounding, methods of manufacture and technical control.

The story of the tyre cord is most interesting and not generally known. It is made of cotton, chiefly grown in Egypt or India. The following points have to be carefully observed:—

(*a*) Hair length and length irregularity.
(*b*) Hair fineness (conveniently expressed as hair weight per unit length).
(*c*) Degree of Maturity.

With regard to (*a*) the fibres are very carefully sorted into various lengths after combing and the quality of the cotton is assessed by the mean length and length irregularity. The result of such an examination is shown in the typical frequency curve of Fig. 37a. Great variation is encountered in mean hair length and in hair-fineness, chiefly between different types of cotton; as an example, the following figures may be quoted as representative of a long-staple Egyptian type and a native Indian cotton.

	Egyptian.	Indian.
Mean Hair Weight per cm. ($\times 10^{-8}$ gram)	160	250
Mean Hair Length (inches)	1.0	0.65

Cottons of the same type also differ in these properties according to the district in which they are grown and, to a lesser degree, according to climatic variations from season to season in any particular district. Generally speaking, the strength of a yarn of given dimensions is greater, the longer and finer the cotton from which it is spun.

The third property mentioned—degree of maturity—is indicated by the degree of thickening of the cell walls. An immature cotton hair is rather like a collapsed thin tube, whereas a mature hair nearly resembles a thick-walled tube of small bore. A high proportion of immature hair is a bad feature; the degree of maturity is influenced by climatic conditions. Careful control is exercised on crops such as the Egyptian, every precaution being taken to maintain the purity of each type of cotton grown. In addition, cotton merchants make selections of each type from particular districts, producing a blend with even characteristics. With such careful control the only disturbing factor is usually a seasonal variation dependent on climatic influences; such variation is not great as a rule and it is sometimes practicable to compensate for it by eliminating the shorter hairs to a greater or less degree in the processes preparatory to yarn spinning. As a result, the average cord strength shows little variation from year to year.

So much for the cotton; now to a typical cord. A yarn is first made from a cotton of the long staple Egyptian type, such that about 19,000 yards weigh one pound. Five such yarns may be twisted together and then, perhaps, three such groups of five twisted together in the opposite direction. The resulting cord will have a diameter of about 0.9 mm. and an average tensile strength, under normal atmospheric conditions, of about 20lb. The design of a

cord varies according to the type of tyre for which it is required; kind of cotton, size and number of yarns, degree of twist at each stage, tension applied in twisting, and so on, may be varied, producing differences in strength, extensibility, weight per unit length, diameter, impact resistance and resistance to fatigue.

The *aeroplane tyre cord* is produced to a special design resulting from much development work; it is chiefly characterised by increased strength per unit weight as compared with other cords. A typical tensile load-elongation diagram to fracture of such a cord is reproduced as Figure 37b; the ultimate tensile strength developed is, approximately, 24 tons/inch^2.

With regard to *failures*, the aeroplane tyres of canvas and the early cord tyres were very liable to concussion or impact bursts, especially as the weight of

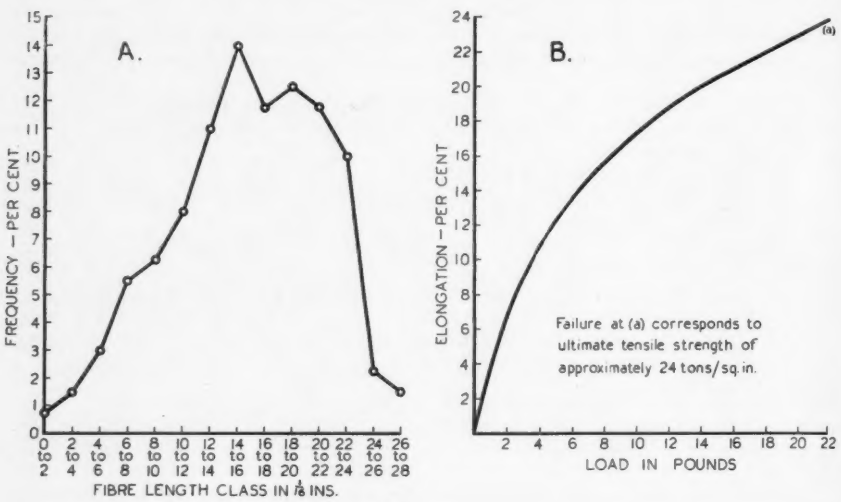

A.
FREQUENCY — PER CENT
FIBRE LENGTH CLASS IN 1/8 INS.
B.
ELONGATION — PER CENT
LOAD IN POUNDS
(a)
Failure at (a) corresponds to ultimate tensile strength of approximately 24 tons/sq. in.

FIG. 37.

A. Frequency curve of fibre length of raw cotton used in aeroplane tyre cord.
B. Tensile load-elongation diagram to fracture of typical aeroplane tyre cord.

machines increased. With the strong but light tyre resulting from modern cord developments, concussion bursts are practically unknown. *Punctures* of tyres are infrequent, but there is always the danger of a pilot being unaware of a puncture until he attempts to land. Accordingly, there have been produced puncture sealing liquids that can be injected through the tube valve and are drawn, by the escaping air, into a puncture or minute cut. The composition really acts as a "mechanical" asbestos filler; consisting of long fibres which "mat" up, effectively clog the hole and stop the leakage. They are of particular value in districts where "camel thorn" is encountered on desert aerodromes and all service machines operating in tropical conditions adopt this precaution.

PART V.

NOTES ON SOME CHARACTERISTICS OF METALS.

1. THE PRIMARY PROBLEM.

The primary problem of metals is of a threefold nature, relating to cohesion, deformation and fracture. All metals are essentially crystalline in their structure, and physical methods have enabled the nature and dimensions of these structures to be determined with great accuracy. But in spite of the great contributions

to knowledge made by atomic physicists, a quantitative theory of cohesion of the metallic state is not yet available, nor does it appear likely that such a theory can be reasonably expected in the near future, owing to the new discoveries regarding the nature of the atom which continue to be made. This being the position of this fundamental aspect, it may appear futile even to discuss whether the observed mechanical properties of metals are consistent or inconsistent with those expected from the particular crystalline structures concerned. Nevertheless, from associated physical characteristics, the indirect inference appears to be generally accepted that the observed technical strengths of metals are much lower than would be expected if this property depended entirely upon the perfect geometrical structure theoretically assigned to the crystalline state. In fact, there is a growing belief that the strength of a practical metal will only be comprehended when studied as a material, essentially crystalline, but modified by the presence of some form of imperfection distributed regularly or at random throughout that structure. Any successful attempt to evolve a mathematical theory of strength, based on such premises and such a modified form of structure, would constitute a notable contribution to knowledge and might have far-reaching practical results.

The subject is of no mere academic interest. The need for materials of greater strengths for aeronautical and other purposes is ever present, while the methods usually adopted to achieve this purpose—by alloying or heat-treatment—produce improvements which, though valuable, are probably insignificant in comparison with what might be attained if the problem could be attacked fundamentally. The property of plasticity in metals, unlike that of elasticity, cannot be reconciled at all with the conception of a perfect crystal, hence plastic deformation, like the supposedly low technical fracture strength, is suspected to result from the presence of imperfections in the structure. Regarding the nature of these imperfections, various theories have been advanced. These include the existence of secondary structures, such as the " superstructure " of Zwicky, the " lineages " of Buerger, the " block structures " of Smekal; also the conception of surface or internal flaws, originally due to Griffith and subsequently made the subject of experiments by Joffé, Orowan and others; more recently, interesting suggestions ascribing the mechanism of plastic deformation to the presence and effect of migratory " dislocations " have been advanced by Taylor, Polanyi and Orowan. A summarised account of these various theories has previously been rendered before this Society in a paper[60] which surveyed the application of physical methods to these problems and described, in some detail, the work of the writer and his colleagues in attacking the problem of the actual mechanism of deformation and fracture of a plastic metal. At that time (April, 1936), the progress achieved may be summarised thus:—It was definitely shown that the process of plastic deformation and failure under any type of applied stressing—tension, compression or torsion, either static or fatigue—involved a destruction of the crystalline structure such that the whole of the material (a mild steel) was in one or more of three conditions only. These conditions were:—(*a*) *Perfect grains*, each giving sharp X-ray reflections, having a grain size of about 10^{-2} cm. and a uniform orientation throughout the grain; (*b*) *dislocated grain*, consisting of relatively large fragments of a grain, oriented to each other at angles not exceeding 2°, thus producing elongated X-ray reflections; and (*c*) *crystallites*, or very small crystal fragments of a constant size (10^{-4} to 10^{-5} cm.), having an entirely random orientation. The sequence of events leading to fracture under static stressing, also to a stable condition resulting from repeated cycles of a safe range of stress, or to fracture under an unsafe range of stress, were fully described in the paper. This research also definitely afforded the first physical explanation of the mechanism of fatigue and established, also for the first time, that the fracture of metals under statical and fatigue stressing is accompanied

[60] " Strength of Metals in the Light of Modern Physics." Gough, H. J., and Wood, W. A., Jour. Roy. Aero. Soc., Vol. XL, 1936, p. 586.

by exactly the same changes in structure. There was one aspect of the fracture condition, however, on which the experiments could not, by their nature, be entirely critical; this was regarded as of fundamental importance and a further research, which has proved successful, was put in hand to clear up the matter. The point at issue was as follows. The previous work *established* that, at the fracture stage and in the *immediate* neighbourhood at least of the fracture, every original crystal had become broken down into a mass of tiny crystallites of uniform size—of a cross-sectional dimension equal to about 10,000 atoms only—and entirely random orientation; the X-ray photographs could also be interpreted as indicating that, at the fracture stage, the material was not only thus fragmented but was in a state of severe internal stress or strain (lattice distortion) and that final failure marked the attainment of a limiting degree of such internal strain. But the conditions of the experiment were such that the presence of this lattice distortion was not definitely established. Here, again, no point of mere academic interest is involved; the matter is of great technical importance as affecting our conceptions of the cold-worked metals in every-day use. For the purpose of obtaining increased strength and hardness, a common method used is to work-harden a steel or non-ferrous metal by rolling, drawing, extruding, etc., and, as is well known, the tensile and fatigue properties are considerably increased in consequence. Yet the research had definitely shown that all such processes *must* produce a fragmented structure; obviously, there was some further secondary effect which marked the vitally important difference between a fragmented structure in the conditions when work-hardened and when fracture was imminent. An improved X-ray technique was therefore developed and we have now repeated the experiments, using a steel *initially* in the cold-rolled and fragmented condition, and studying the progressive changes which marked the approach to the fracture stage. Full reports on this work have recently been published elsewhere,[61 62] and it will be sufficient to record the essential result. It was definitely established that the process of fragmentation is, in itself, essentially a *strengthening* effect, assisting the material to resist or retard further changes due to the applied stressing system. If under that stressing system, the structure attains a state of equilibrium, fracture is indefinitely postponed. But if the applied system is such that fracture will eventually be produced, then a progressive change occurs in the intensity of the X-ray reflections. No further radial diffusion appears—such as would indicate a further break-up of the crystallites—neither, under the conditions of the experiments, is any indication afforded of a preferred state of orientation of the crystallites. But the intensity of the ring, forming the X-ray photograph, becomes more and more diffuse as the test proceeds and this is only to be accounted for by the incidence of heavy lattice distortion in the structure of the crystallites. Thus, the experiments conclusively cleared up the point outstanding and the fracture stage of steel—and probably of other metals now being examined—can be regarded as the attainment of a certain limiting and critical degree of internal strain in the previously fragmented material.

It is hardly necessary to point out that the observed critical *size* of the crystallites and the apparent ease with which they can be *rotated* in the metal without the *cohesion* of the mass being destroyed (except in the ultimate state) lends increased weight to the conception of the presence of regularly distributed internal flaws in the material. The implications of the existence of such a sub-structure on the possibilities of improved metals for aircraft construction are most interesting and are worthy of a moment's reflection. Supposing that it is found possible, at some time, completely to remove such imperfections, what sort of a material might result? We would expect to get a great increase in breaking strength—

[61] "The Crystalline Structure of Steel at Fracture." H. J. Gough and W. A. Wood, Proc. Roy. Soc., A, No. 922, Vol. 165, pp. 358/371, April, 1938.

[62] "The Deformation and Fracture of Metals." H. J. Gough and W. A. Wood, Jour. Inst. Civ. Engrs., No. 5, 1937/38.

to what extent cannot even be guessed, but it might be, say, a thousandfold. Assuming pure iron has a practical tensile strength of about 15 tons/inch^2, a material of 15,000 tons/inch^2 tensile strength might result. It should be perfectly elastic and so could not be worked in any way, which might be a serious practical disadvantage. When changes of section occurred, the full theoretical stress concentration would, no doubt, be exhibited, although this might not matter very much, as a very considerable *nett* increase in strength would be derived. So the perfect metal would be subject to definite disadvantages for constructional purposes. What appears more attractive to the writer are the advantages likely to be gained from a " control " of the intrinsic flaws. One can so easily visualise a material allowed to have such a sufficient degree of imperfections as to allow of fabrication but still possessing a much higher strength. What a boon would be a metal having, say, a 1,000-ton tensile strength and a moderate capacity for plastic deformation! At the present time, such materials must be regarded as fanciful possibilities but, *as* possibilities, research of a fundamental nature in this and similar directions should be intensively pursued; even if the long chance is not brought off, new information of scientific and practical value is *certain* to result.

2. Fatigue.

As the stressing systems to which aircraft components are exposed are rarely of a static nature, the fatigue aspects of the aircraft materials assume considerable importance. The subject of fatigue is much too wide to be dealt with in a general manner in the present lecture; for such purposes, reference may, perhaps, be made to a series of critical surveys[63] which include references to much of the literature on the subject. The present notes aim rather at directing attention to the more important present-day fatigue problems especially relating to aircraft construction, which are deserving of research attention. In the opinion of the writer there are four aspects which should receive concentrated attention, as much data directly applicable to aircraft practice would certainly result. These may be described:—

(1) Investigation of Size Effect.
(2) Further Studies of Stress Concentrations.
(3) Methods of Application to Design.
(4) Combined Stresses.

(1) Investigation of Size Effect.

The era of systematic testing really dates from the latter half of the 18th century and a very great proportion of the early work was carried out on full sized components, mostly of a structural nature. The reason was that no theory of elasticity was then available and the primary object of the tests was to check the correctness of design principles. With the development of rational theory and the introduction of new materials, testing tended more and more to be confined to small specimens to ensure that the material was satisfactory. Full sized testing is still sometimes employed—that undertaken in connection with

[63] (1) Gough, H. J. " The Fatigue of Metals." E. Benn, London, 1924.
(2) Gough, H. J. " Fatigue of Metals and Alloys." Inter. Crit. Tables, Vol. II.
(3) Gough, H. J. " Fatigue Phenomena." Cantor Lectures, Jour. Roy. Soc. Arts, Feb., 1928.
(4) Gough, H. J. " Fatigue of Metals." Proc. Inter. Assoc. Test. Mat., Zurich Congress, 1931.
(5) Gough, H. J. " Corrosion-Fatigue." 11th Autumn Lecture, Jour. Inst. Met., Vol. 49, No. 2, 1932.
(6) Gough, H. J. " Crystalline Structure in Relation to Failure of Metals." 8th Edgar Marburg Lecture, Proc. A.S.T.M., Vol. 33, Pt. 2, 1933.
(7) Gough, H. J. and Wood, W. A. " Strength of Metals in the Light of Modern Physics." Jour. Roy. Aero. Soc., August, 1936.
(8) Gough, H. J. and Wood, W. A. " Deformation and Fracture of Metals." Jour. Inst. Civil Engrs., No. 5, March, 1938.

the members of the Sydney Harbour Bridge is a well-known example—but, in general, it is assumed that a laboratory test on a small carefully prepared sample reflects faithfully the characteristics of the full sized part. But there is a growing appreciation—which, unfortunately, is not yet general in this country—that misleading results may be obtained from small samples, especially under fatigue conditions and that much more full-scale testing is very desirable. Some of the reasons for this belief are obvious:—In many designs of complicated shapes and loading conditions, the induced stress system is still very difficult, if not impossible to evaluate; owing to surface effects caused in manufacture and the mass effect in heat treatment, tests on small specimens may be misleading; some processes, such as welding, cannot be " scaled-down "; errors in workmanship, as in thin-walled constructions in aeroplane spars or large riveted structures, may have important effects, etc. For investigation of such factors only, it is high time that an organised attempt was made, in this country, to instal fatigue testing machines of much larger capacity, particularly with regard to size.

But it is desired especially to draw attention to the unsatisfactory position regarding " scale " effect, as such. The problem can be simply stated; we require to know whether, given a series of geometrically similar components of various sizes, subjected to equivalent cyclic stressing systems, a single value of the fatigue limit would be obtained. It is convenient to scrutinise the available evidence in two categories, relating to smooth cylindrical specimens, also, specimens containing discontinuities of section.

Considering specimens *free* from sudden changes of form, the most complete set of data are those due to Peterson. He fully realised the difficulties involved and took every precaution to ensure that the material used in each series of tests could be regarded as of constant properties. His results are given in Table XI. Making allowance for unavoidable small variations that must be expected in tests of this sort, no very important size effect appears, although there is an indication of a tendency for the fatigue limit to decrease, by an amount not exceeding 10 per cent., as the specimen size *increases* from 0.05in. to 2in. In 1933, Faulhaber reported that the fatigue strength of a mild steel, tested in 0.296in. and 1.08in. diameters, suffered a reduction of 6 per cent. in the larger sizes, while other tests on steels of greater tensile strength are said to have shown drops of from 4 to 15 per cent. for these sizes. Lehr confirms these results and mentions tests on specimens of 0.375in. and 1.18in. diameter, reductions of 12-16 per cent. being found in the larger sizes. Mailander and Bauersfeld have made a carefully conducted investigation using torsional stresses on hollow and solid specimens of an alloy steel; with increase in diameter from 0.55in. to 1.77in. the fatigue limits steadily decreased. A similar result is reported by Horger using bending stresses. All these results, with some others, are given in Table XI. They show that the position is rather unsatisfactory, but, taking them as a whole, it must be accepted that a size effect exists in fatigue and should be recognised in design. It is not at all clear why this should be so. Cold working of the surface during polishing may have an influence, also, the desired conditions of geometrical similarity obviously do not extend to the crystal size. If the effect is a real one, then, in some cases, the application of test results obtained on the usual laboratory specimens of about $\frac{1}{2}$in. diameter would be liable, if applied to very large sizes, to give very misleading results.

It has been considered desirable to review in some detail the evidence concerning size effect in fatigue on *smooth* specimens because there is a general impression that with such specimens, the effect of size can be ignored. The evidence quoted in Table XI will show that this conclusion cannot be accepted, also that the subject should be further investigated.

Turning to specimens or components containing discontinuities of section causing stress concentrations, it is generally accepted—at least among those who have made a study of fatigue—that a marked size effect undoubtedly exists. All the existing reliable data point to the same conclusion, namely, that as the size

TABLE XI.

SIZE EFFECT: EXPERIMENTS MADE USING POLISHED SPECIMENS FREE FROM SUDDEN CHANGES OF FORM.

TABLE XI.

SIZE EFFECT: EXPERIMENTS MADE USING POLISHED SPECIMENS FREE FROM SUDDEN CHANGES OF FORM.

Investigator	Fatigue Stressing Employed		Material	Sizes of Specimens Used (diameters in inches)	Fatigue Limits tons/in²	Ratio	Remarks
Moore (1927)	Reversed Bending (Rotating Bar)		0.46% C. Steel	0.3	±15.6	1.00	Specimens *not* geometrically similar: marked stress concentration at fillet of larger specimen.
				1.0	±10.7	0.67	
Moore, Lyon and Alleman (1929)	do.	do.	C. Steels containing 0.45% to 0.55% C. (2 typical results only quoted)	0.3	±18.3	1.00	Specimens *not* geometrically similar: marked stress concentration at fillet of larger specimen.
				1.0	±13.0	0.72	
				0.3	±16.1	1.00	
				3.0	±11.6	0.72	
Peterson (1930-1933)	do.	do.	0.19% C. Steel	0.05	±11.9	1.00	
				0.273	±12.3	1.03	
				1.00	±10.7	0.90	
			0.42% C. Steel	0.05	±14.8	1.00	
				0.273	±14.3	0.98	
				0.469	±14.5	0.99	
				1.00	±15.1	1.02	
			0.44% C. Steel	0.05	±15.6	1.00	
				0.273	±15.9	1.02	
				0.469	±14.9	0.95	
				1.00	±14.0	0.90	
				2.00	±14.2	0.91	All specimens geometrically similar.
			0.45% C. Steel	0.05	±14.3	1.00	
				0.469	±15.4	1.07	
				1.00	±15.6	1.09	
				2.00	±15.6	1.09	
			0.57% C. Steel	0.05	±21.4	1.00	
				0.469	±21.9	1.02	
			Cast Iron No. 1	0.05	± 4.5	1.00	
				0.469	± 5.6	1.25	
			Cast Iron No. 2	0.469	± 4.3	1.00	
				2.00	± 4.3	1.00	
Faulhaber (1933)	do.	do.	0.1% C. Steel	0.296	±17.0	1.00	Geometrically similar specimens.
				1.08	±16.0	0.94	
Faulhaber, also Lehr (1933-1935)	do.	do.	Various Steels	0.296 to 0.373	Various Values	1.00	Complete details not yet available.
				1.08 to 1.18		0.84 to 0.88	
Mailander and Bauersfeld (1934)	Reversed Torsional Stresses		Cr-Ni-W Steel	Solid 0.55	±17.7	1.00	
				Solid 1.18	±14.9	0.84	Geometrically similar specimens
				Solid 1.77	±12.7	0.72	
				Hollow 0.55	±15.2	1.00	
				Hollow 1.77	±12.0	0.79	do. do. do.
Horger (1935)	Reversed Bending (Rotating Bar)		0.47% C. Steel	0.3	±17.7	1.00	
				1.0	±16.1	0.91	Geometrically similar specimens.
				2.0	±15.3	0.86	

of the specimen increases, the *reduction* in fatigue strength caused by the presence of the discontinuity also increases. It will be sufficient to quote a few typical examples to show the magnitude of the effect; all relate to geometrically similar series of specimens.

Let K = realised stress concentration factor.
= fatigue limit with smooth specimens/fatigue limit when a discontinuity is present.

	Type of Specimen	Dia. of Specimen (inches)	Value of K
0.45% C. Steel	1. Round Specimens with circular diametral hole ($d/D=\frac{1}{4}$)	$\frac{1}{4}$	1.2
		3	1 56
	2. Ditto ($d/D=\frac{1}{16}$)	$\frac{1}{2}$	1.35
		3	1.84
0.57% C. Steel	3. Round Specimen with circular diametral hole ($d/D=0.15$)	$\frac{1}{4}$	1.38
		$2\frac{1}{8}$	2.22
	4. Round Specimen with radius fillet ($r/D=0.15$)	$\frac{3}{8}$	1.50
		$2\frac{1}{8}$	1.75

It may be noted that the full results of the investigations (due to Peterson), from which the above typical results are abstracted, when plotted as relations between "K" and specimen diameter, show a tendency to approach a limiting value, which in some cases corresponds to a diameter of about 3in., which happens to be the practical size to which particular interest attaches with regard to aero engine crankshafts.

(2) Further Studies of Stress Concentration Effects.

There is now an extensive literature relating particularly to British, American and German research on the reduction in fatigue strength when discontinuities are present. In spite of this, much further research should be carried out. In the first place, the drop in strength is not merely a function of the *shape* of the discontinuity as theory would indicate; the actual influence of any one type of discontinuity varies with the material employed and, hence, more work is required on some of the modern steels and light alloys which have hitherto escaped attention. Then again, the available data relates entirely to simple stressing conditions which do *not* relate to actual engine conditions; there is an urgent need for data relating to *combined stresses*.

The subject is really very important; it is true to say that the actual performance of most components depends not so much on the intrinsic fatigue properties of the materials but on the modifications of these values when the inevitable fillets, holes, screw threads, etc., are present.

(3) Methods of Application to Design.

It is an unfortunate fact that sufficient use is not yet made of the results of analysis and photo-elastic methods in reducing the diminution of strength caused by the inevitable discontinuities of section. Neither is it sufficiently realised that such effects can often be relieved by *taking off* material rather than by building up the section in these regions. The study of what are termed "stress flow lines," based on hydrodynamical analogy, photo-elasticity, or electrical analogy, has been extremely valuable in indicating the stress relief that is possible by a modification in shape; the method aims, in fact, at "streamlining" the stress flow lines. Among the devices which have been developed for this purpose may be mentioned tangential relieving grooves and relieving collars at radial oil holes; properly designed transition fillets and re-entrant fillets at collars, bosses, etc., specially designed thread forms, etc.

Serious stress concentration effects often occur at shrink and press fits. Much stress relief can often be obtained by improved design, while previous surface compression or surface rolling have afforded marked improvement in many cases.

Much laboratory research work into these aspects and much resulting application to practical design has already been accomplished, but mostly abroad and

particularly in the United States and Germany. This note cannot do more than draw attention to this important aspect; the author will be pleased to supply a selected bibliography of relevant references in the technical literature to those especially interested.

(4) Combined Fatigue Stresses.

In spite of the practical importance of the subject and of the vast amount of attention that has been devoted, throughout the world, to various aspects of fatigue, it is only recently that a systematic study of the resistance of materials to combined fatigue stresses has been commenced. Under the auspices of the Department of Scientific and Industrial Research, the writer was able to attack this problem and a high speed combined fatigue testing machine was successfully developed. The machine is designed to apply cycles of reversed stresses, simple bending and simple torsion or any desired combination. A description of this machine and some of the results obtained have been published[64] while other papers will appear shortly. The fatigue results obtained with all the ductile metals so far investigated have proved to conform to a very simple law—which has been termed the " ellipse quadrant "—while brittle materials also conform to a simple relation. It was realised that the successful development of a high speed combined stress fatigue testing machine satisfied a long felt want and, in the interest of technical knowledge, the approval of D.S.I.R. was obtained to offer every facility to research laboratories and industry to avail themselves of the new development. The drawings of this machine have now been issued, without charge, to a large number of applicants and many aircraft manufacturers in this country have now installed a battery of these machines, while similar facilities have been afforded in the United States, France, Germany and Switzerland. Results are now becoming available and, in a few years' time, a very considerable amount of published data, relating to a wide variety of aircraft and other materials, should have been made available to designers. It may be of interest to record that, on behalf of the Air Ministry, a further development of this machine has now been made, in which four independent variables—two types of alternating stress and two types of static mean stress—can be simultaneously imposed, thus enabling, for the first time, a study to be made of the fatigue resistance of materials under every stress condition met with in an aero engine crankshaft. It is hoped shortly to publish an account of this machine and some of the results obtained.

Thus, a satisfactory entry has now been made into this important field of combined fatigue stresses. But many other types of combined stressing remain to be explored and there is thus available a rich field for much research of a most interesting nature and one which will yield data possessing both scientific and practical importance.

3. Fretting Corrosion.

The term " fretting corrosion " is used to denote the mutual corrosion and deterioration of metal surfaces in closely fitting contact and subjected to vibration which is an essential condition. It is a frequent and most annoying source of trouble in many branches of engineering practice; in aircraft engineering, serious deterioration of this kind has been encountered in ball races, bearings, airscrew shafts, hubs of gears, and numerous other components. Many references to this action will be found in the literature, where it is variously described as " seizing," " formation of cocoa," " contact erosion," " brinelling," etc., but the term used above is recommended as most suitable to describe the action and to avoid confusion with other actions which are not really related to this particular

[64] Gough, H. J., and Pollard, H. V.
1. Proc. Inst. Mech. Engrs., Vol. 131, 1935.
2. Proc. Inst. Mech. Engrs., Vol. 132, 1936.
3. Jour. Inst. Auto. Engrs., 1937, No. 6, Vol. 5

trouble. Components of machines that are firmly assembled together, including force and shrink fits, apparently beyond the possibility of any relative movement and, therefore, of ordinary wear, are commonly found to have their bearing surfaces badly eroded after a period of use; when the materials are steel, as is commonly the case, the surfaces are generally found to be coated irregularly with a layer of reddish oxide debris. The fitting surfaces are often found to be too much damaged to be reassembled and replacement of the components is necessary, although, in all other respects, they may be quite serviceable. It is a peculiar feature of the phenomenon that the most highly finished surfaces and the best types of fit appear to be most susceptible, although, of course, it may be that damage which is quite obvious on a well-finished surface would not be so noticeable on an ordinary machined surface.

A physical explanation of what is happening when fretting corrosion is in operation has not yet emerged and the trouble seems to have been accepted in practice as one of those which must be put up with in certain circumstances. As the result of much experience, certain measures are taken in practice to reduce the amount of damage and these have proved well worth while. But fretting corrosion remains an obscure phenomenon and is receiving systematic research attention at the present time at the National Physical Laboratory.

The measures taken in aero engine practice to reduce the harmful effects may be summarised thus :—

(*a*) Since fretting corrosion most commonly results from relative movement of loaded mating surfaces, means are adopted to increase the pressures between such surfaces to a value well in excess of the actual working pressure required. As one example may be mentioned the assembly of the top and bottom halves of a crankcase where the bolting forces must be sufficient to unite by friction the two mating surfaces. Other examples of a similar nature are the use of tapers on shafts for the mounting of wheels and similar parts, also the use of split taper collets, etc., for pre-loading.

(*b*) Then the design and construction are often modified so that pre-loaded surfaces in other planes are introduced with the object of eliminating altogether the possibility of movement under load of the surfaces as a whole. As examples of this method we may recall the use of Vee serrations instead of flat faces for uniting two pieces bolted together, also the bolting of pieces in two planes mutually perpendicular.

(*c*) In cases where it is impossible to use positive means of preventing small movements between mating surfaces under load, some form of surface treatment is used, such as hardening, plating, tin coating or the interposing of some softer material, metallic or non-metallic. In this category fall steel housings and unclamped shaft mountings where the load is such as to cause an epicyclic creeping effect of the ball and roller races relative to the mountings. For clamping airscrew blades, special soft metal collets or even oiled silk have been used. In the case of a propeller hub shell mounted on a centre having a fixing flange at one end, the slight relative movement between the shell and the centre of the other end has been satisfactorily provided for by tin coating one of the surfaces. A further most interesting application, which has proved most successful, is the insertion of a synthetic fabric reinforced sleeve between the magnesium blade and the airscrew hub, previousy referred to in Part IV, Section C, and illustrated in Fig. 35c.

It was mentioned above that systematic research into this most interesting and important problem is in progress at the N.P.L. on behalf of the Air Ministry. Two main lines of investigation have been followed to date. In the first, annular rings were employed, threaded on a common shaft and pressed together by a spring-loaded axial force, neighbouring rings being subjected to cycles of alternating torques of various controlled amounts, some of which were sufficient to cause alternating slipping between the contacting surfaces. To obtain a study of the process under more precise conditions of control, the investigation was

then extended to experiments employing spherical and plane surfaces in contact, also flat surfaces in contact. These experiments were made under various combinations of materials both in the dry and lubricated conditions. It has been established that actual relative slip between the mating surfaces is an essential condition for fretting corrosion although the amount of slip required is very minute; a few millionths of an inch is sufficient to produce rapid corrosion with oxidation debris. This occurs irrespective of whether the surfaces are clean or oiled; the presence of oil did not in any case prevent corrosion although it generally modified the effect. Softer materials show, in general, more tendency to seize and less tendency to produce corrosion debris than the hard steels. The amount of corrosion produced is not greatly influenced by the intensity of normal pressure on the contact surfaces; there is certainly no kind of systematic proportionality between the pressure and the resulting damage. With regard to combinations of materials, some pairs were more effective than others, but, in every case, corrosion was produced if the tests were sufficiently extended. Where brass forms one material of a pair, the minimum corrosion was produced, while stainless steel in any combination appears to be the worst offender. A full report on this investigation will be published in the near future and further experiments are in progress.

4. Abrasion and Wear.

The avoidance of abrasion and wear is one of the most important problems facing the engineer and it has therefore received much experimental attention in many laboratories. And yet we probably know less about the true nature of wear than any of the other primary problems relating to materials, certainly less than about fatigue, creep, or even corrosion. The fact is that the term " wear " covers such a wide range of operating conditions that it is extremely difficult and dangerous to apply the lessons learnt from one series of experiments to service conditions which these do not exactly simulate; when the state of knowledge of a subject is of that type, it can truly be described as merely empirical. But the facts are not generally recognised; the writer regularly receives requests for advice concerning the " best " type of wear tester. That this is no mere personal opinion of dissatisfaction may be shown by recent references in the technical literature.[65] A most excellent Discussion on " Wear of Metals " took place in April, 1937, organised by the American Society of Testing Materials, centring round a valuable series of papers dealing with wear from many aspects and relating to many industries, automobile, power equipment, textile, railway, etc. Among those papers is one by Dr. Gillett in which many significant references to the present state of knowledge are made. One is especially well worth quoting; he says:—" Despite all the thought and work on the subject and all the published articles, we are, broadly speaking, still a long way from being able to predict with the assurance required for reasonable engineering precision what the relative lives of two metals will be in service and we especially lack the ability to put a new alloy, on which service experience is lacking, into its correct position in a list of wear resistant alloys on the basis of some laboratory test. In the evaluation of corrosion resistance, it is beginning to be realised that there is no such thing as corrosion resistance inherent to a metal, apart from the particular corroding medium which is to meet the metal in service. To build an alloy to resist corrosion, one must first understand the mechanism of corrosion in the particular service for which it is intended. In any such statement, one may replace the word ' corrosion ' by the word ' wear.' . . . There is no such thing as a standard wear test and there ought not to be. Instead, let us each build wear test outfits as we need them, intelligently designed to simulate the particular service we want to improve. Our aim must be in the classic words of Gilbert and Sullivan ' to make the punishment fit the crime.' " Simultaneously with

[65] " Symposium on Wear of Metals." A.S.T.M., April 5th, 1937.

the discussion in America, the International Association for Testing Materials was holding a Congress in London where considerable attention was also being given to the information regarding wear and wear-testing, supplied in papers contributed by British, French, German, Austrian, Japanese and American authors. The state of knowledge revealed can perhaps be gained from the summarising remarks of the Group President, Professor Benedicks, who wrote[66]:—" As for wear in general, several important contributions were given. That wear presented a great similarity to corrosion was well brought out. Both phenomena were actually very complicated. Just as it was impossible to develop a universal method for corrosion testing, so it must be impossible to find a universal method for wear testing. In both cases, substance was removed from the surface of an object; in wear, essentially by varying mechanical forces; in corrosion, essentially by varying chemical forces. The testing method must adapt itself to the forces at hand." To the London Congress was submitted a paper, by H. E. Smith, describing the results of an experimental study of some of the essential features of the abrasion of metals which had been in progress for some years at the N.P.L. A special machine had been designed for this work and specimens could be subjected to pure rolling abrasion, pure sliding abrasion, or to rolling abrasion with various percentages of slip. The effects of various degrees of humidity (a most important factor), unequal abrasive action due to the adhesion of debris to the specimens, effect of environment, etc., were carefully investigated. The author concludes by remarking that " the fundamental principles upon which scientific abrasion testing should be based have yet to be discovered."

Nevertheless, the attack on the problem of abrasion and wear should be actively pursued using physical methods. A notable contribution[67] to the subject was published recently which reveals the ultimate possibility of a successful solution. A new approach was made to the problem, three main lines of investigation being followed. An X-ray examination of wear products from abraded steels showed that the crystal structure can be completely broken down, indicating severe stressing during sliding contact; a study of contact temperatures and of the violently fluctuating value of the frictional force, acting between dry metallic surfaces, indicated the existence of such severe stressing that suggested a type of surface fatigue breakdown; increasing temperatures were found to cause large increases in the hysteresis loss of steels subject to alternating stresses, while the high internal damping, at temperatures up to 800°C., led to important conclusions regarding the surface wear process. The author is led to conclude that the high temperatures on sliding steel surfaces are caused by highly damped surface fatigue action as much as by the shearing of metallic " bridges " formed at the points of contact and, further, that these high temperatures result not only in the initial formation of the characteristic " wear rust " but finally lead to localised fatigue failure and resultant surface wear.

5. Damping Capacity.

Once upon a time, it was believed that if a specimen could withstand cyclic stressing indefinitely and without fracture, truly elastic conditions only were operating; a very convenient theory which avoided many troublesome explanations. Two assumptions are implied:—(1) that no permanent change occurs in the dimensions of the specimen, and (2) that, in any one cycle, a single value of strain is associated with any one value of stress irrespective of whether the specimen is being loaded or unloaded. The first assumption was disproved as early as 1881, by Bauschinger, while Ewing, in 1889, showed that, even under very small stress cycles, perfect elasticity did not exist and that strain hysteresis must be accepted as a property of metals. It had not yet been proved, of course, that these occurrences persisted for many millions of cycles; that proof was left

[66] Proc. Inter. Assoc. Test. Materials, London Congress, April, 1937.
[67] " The Mechanism of Wear in Metals." T. U. Matthew. Jour. Roy. Tech. College (Glasgow), Vol. 4, Pt. 2, Jan., 1938.

to the approximate period 1910-1923, when, owing to the work of Bairstow, Gough, Mason and Haigh, it was clearly established that the association of freedom from fatigue only with the truly elastic state was no longer tenable. But the idea died hard. After all, engineering design was and still is based mainly on elastic theory and the new school of heretics was often dismissed with the accusation of inaccurate measurements of what are, admittedly, extremely small strains. The new conception of strain hysteresis was also apparently at variance with the thermodynamics of strained metals. Most substances and nearly all metals, expand on heating and contract on cooling and, hence as Joule and Kelvin showed, assuming perfect elasticity, cold is produced when a metal is strained by opposing any internal elastic force and heat when it yields to that force, so that under cyclic stresses, the average temperature should not vary. Now the existence of strain hysteresis within the fatigue range means that a metal can, without fracture, transform into heat really enormous quantities of mechanical work and the sceptic asked, with reason, how this was possible. I suppose there is, even to-day, no generally accepted explanation, but of the facts there can be no doubt. In certain quarters, therefore, the idea was dismissed as fantastic, and those of us who had studied the subject were regarded as " voices crying in the wilderness." But, in the post-war impetus given to fatigue testing, the sceptics received further shocks. They were faced with the experimental fact that the theoretical values of stress concentration were not usually realised under cyclical stressing and that the response to notch sensitivity, for example, varied from material to material; also, it was realised that the different degrees of damping of resonant vibrations in various metals were quite inexplicable on elastic theory. During the last ten years, strain hysteresis has been " rediscovered " and under the name of " damping " has received much serious study; unfortunately some of the lessons learned from the earlier established experimental work appear to have been overlooked. It is often stated, as though it was an established fact, that high hysteresis is accompanied by low notch sensitivity and vice versa; it has also been suggested that fatigue strength should often be sacrificed in favour of energy absorption properties. I cannot help feeling that the pendulum has swung too far in the other direction and that it is just as futile to over-exaggerate strain hysteresis as to deny its existence.

In certain circumstances marked strain hysteresis, or—to use modern jargon—damping capacity, is undoubtedly a useful property. Where resonant vibrations occur, the power of energy absorption, as such, by the material is most valuable. But for most metals, the width of the loop is *very small* and fairly accurate extensometers are required to reveal its existence; this fact does not seem to be realised except by those who have traced such loops and statements and arguments are often made which appear to be based on the misconception of a loop in steel, similar in width and area to that exhibited by wood or rubber when cyclically stressed. So that if we put side by side two exactly similar samples of steel, one which is perfectly elastic (if such could be found), the other exhibiting strain hysteresis, and then subjected both to a reasonable degree of strain, such as would normally be imposed under the working conditions of, say, an engine crankshaft, the elastic sample would certainly be subjected to a higher *stress* than its companion. But the percentage difference would actually be *very small*; prevailing misconceptions on this point are sometimes so entirely outside the true facts as to be ludicrous. The present position appears to be that the supposed advantages of " damping capacity " threaten to be a fashionable fetish, often advanced, one suspects, to detract attention from shortcomings of other types in the material in question. While retaining an entirely open mind to what the many current investigations in progress on damping capacity of materials may reveal, it is really necessary, in the meantime, to keep to the solid ground of long established experimental results. For example, a loop traced once or a few cycles only, using a range of stress which involves actual plastic deformation, may give an entirely misleading impression as to the behaviour of the material in service; for, if such a loop

is repeated cyclically, the material may fatigue, while, if fatigue failure does not occur, the width of the loop will certainly diminish and the first and one-thousandth loop will, in general, be entirely different in area. The effect of *rest* is, also, a most important influence and, in short, there are a number of features about the cyclical behaviour of metals which should be recognised before too generous an appreciation of the merits of strain hysteresis is expressed. There is really little excuse for ignorance on this subject, which has been so extensively studied, undoubtedly the best work being that performed in this country in the approximate period 1910-1925.

The statement has been made (*not* in this country) and has attained wide publicity that " damping capacity is likewise a measure of notch sensitivity under fatigue in the sense that if the damping capacity increases, the notch sensitivity under fatigue falls off." The author concerned has never offered any experimental proof of this statement which, if true, would be most important. The writer, therefore, made a most careful search of all available literature for such experimental verification. The only set of critical experiments which could be found were those of Brophy[68] who examined the damping characteristics and endurance properties of several steels in several conditions of heat-treatment, also, of two cast irons and attempted to correlate these properties. The damping capacities were determined using the Föppl-Pertz method of free torsional vibrations; the fatigue limits of both smooth and notched specimens were determined by endurance tests in the ordinary type of Wöhler machine. The results of this really important investigation are given in a most illuminating diagram, to which the attention of all who are interested in this subject may usefully be directed. From this diagram one can at will argue that high damping capacity is directly *or* inversely proportional to the notch sensitivity under fatigue and it is clear that a general statement of either type is equally foolish. The investigation of the true relation, if any, existing between these two quantities is of real practical importance in relation to aircraft materials and a careful study on these lines is in progress at the N.P.L. and is well worth several other independent investigations.

The present note will have served its purpose if it sounds a note of warning against too simple acceptance of many current fairy tales regarding the merits of high damping capacity as a panacea for a most amazing variety of ills.

ACKNOWLEDGMENTS.

The preparation of this lecture has been very greatly facilitated by most generous collaboration afforded in valuable suggestions and advice, data, specially-prepared photographs and sketches and a most interesting series of exhibits of materials and components; I desire to record my most grateful thanks to all concerned for the very great assistance rendered. Space considerations alone forbid individual reference to these contributions and it must suffice to record my acknowledgments to the following individuals and their associates:—Dr. L. Aitchison, Captain F. S. Barnwell, Messrs. G. E. Beharell, R. H. Bound and Griffith Brewer, Dr. N. A. de Bruyne, Messrs. H. L. Cox and G. Cunninghame, Dr. C. H. Desch, Messrs. W. C. Devereux, W. D. Douglas, A. G. Elliott, A. H. R. Fedden, M. Goldschmidt and S. C. Hart-Still, Dr. W. H. Hatfield, Messrs. A. A. Heath and F. Heywood, Dr. W. Ker-Wilson, Messrs. C. P. Lipscomb, N. J. L. Megson, H. L. Milner and A. J. Murphy, Dr. W. J. S. Naunton, Messrs. J. D. North and C. D. Philippe, Dr. D. R. Pye, Messrs. A. E. Skan and F. R. C. Smith, Dr. C. J. Smithells, Dr. H. Sutton, Mr. F. M. Thomas, Dr. Vernon, Mr. C. C. Walker, Dr. H. C. Watts, Captain G. S. Wilkinson, Dr. S. S. Woolf, Messrs. Orville Wright, G. F. Young and R. T. Youngman. Acknowledgment is also made for permission to reproduce certain illustrations:—To the Editor of " Flight " (Figs. 5, 19, 35b and 35d), to the

[68] Brophy, G. R. Trans. Amer. Soc. Metals, Vol. 24, No. 1, March, 1936.

Director of the Science Museum (Figs. 1 and 14) and to the Air Ministry (Fig. 30). Finally, I would record my indebtedness to my colleague, Mr. W. J. Clenshaw, B.Sc., for most valuable assistance rendered in every stage of the preparation of the lecture.

The CHAIRMAN: They had listened to a most remarkable summary in the short time of one hour, of a still more remarkable lecture which, if Dr. Gough had delivered it *in extenso*, would have occupied three hours or more to read. His duty of proposing a vote of thanks was not a mere formality, it was a very genuine pleasure, following the reading of a lecture which was possibly, in the way it was delivered and in its subject matter, one which would become the bible of the aeronautical engineer for many years to come.

Mr. D. R. PYE, F.R.Ae.S., Vice-President: It was also a very real pleasure and an honour, indeed, to be called upon to second the vote of thanks to Dr. Gough for a lecture which he could only describe as a brilliant *tour de force*. This was almost Dr. Gough's swan song as in a few days' time he would be relinquishing the post he had filled with such distinction at the National Physical Laboratory in order to take up the newly formed post of Director of Scientific Research at the War Office.

The vote of thanks was given with hearty acclamation.

The lecture was followed by the Annual Council Dinner at which the following were present:—

Mr. Griffith Brewer, Hon.F.R.Ae.S.

Major J. S. Buchanan, C.B.E., A.M.I.Mech.E., F.R.Ae.S., Chairman of the Finance Committee.

Major G. P. Bulman, O.B.E., B.Sc., M.I.A.S., F.R.Aé.S., Assistant Director (Engines) of Research and Development, Air Ministry.

Mr. S. Camm, F.R.Ae.S., Director and Chief Designer, Hawker Aircraft, Ltd.

Mr. H. Roxbee Cox, Ph.D., D.I.C., B.Sc., F.R.Ae.S. (Chief Technical Officer, Air Registration Board).

Mr. W. C. Devereux, F.R.Ae.S. (Managing Director of High Duty Alloys, Ltd.).

Dr. C. H. Desch, Ph.D., F.R.S., F.I.C., F.I.Ph., President of the Institute of Metals.

Mr. Van Dusen, Vice-President Consolidated Aircraft Corporation.

Mr. C. R. Fairey, M.B.E., F.R.Ae.S., Past-President.

Mr. A. Gouge, B.Sc., F.R.Ae.S. (Director, Chief Engineer and Chief Designer, Short Brothers, Ltd.).

Dr. H. J. Gough, F.R.S., M.B.E., Lecturer.

Mr. A. H. Hall, C.B., C.B.E., M.Inst.C.E., M.I.M.E., F.R.Ae.S. (Chief Superintendent, Royal Aircraft Establishment) (Vice-President).

Commander W. K. Harrill, Assistant Naval Attaché (for Aviation) at the American Embassy.

Professor G. T. R. Hill, M.C., M.Sc., F.R.Ae.S., Professor of Engineering, University College.

Mr. J. E. Hodgson, Hon.F.R.Ae.S. (Honorary Librarian, Royal Aeronautical Society).

Lord Kenilworth, C.B.E., F.R.Ae.S.

Colonel E. E. B. Mackintosh, D.S.O., Director of the Science Museum.

Colonel Lindbergh.

Sir George Lee, O.B.E., M.Sc., President of the Institution of Electrical Engineers.

Mr. Glenn L. Martin, President of the Glenn L. Martin Aircraft Corporation.

Lieut.-Colonel J. T. C. Moore-Brabazon, M.C., M.I.Ae.E., F.R.Ae.S., M.P., Past-President.

Mr. F. Handley Page, C.B.E., F.R.Ae.S. (Managing Director, Handley Page, Ltd.) (Vice-President).

Dr. N. A. V. Piercy, M.Inst.C.E., M.I.Mech.E., F.R.Ae.S., M.Cons.E. (Head of Aeronautical Department, Queen Mary College).

Professor A. J. Sutton Pippard, M.B.E., D.Sc., M.Inst.C.E., F.R.Ae.S. (Professor of Civil Engineering, City and Guilds Engineering College).

Captain J. Laurence Pritchard, Hon.F.R.Ae.S. (Secretary, Royal Aeronautical Society).

Mr. D. R. Pye. C.B., F.R.S., M.A., Sc.D., M.I.Mech.E., F.R.Ae.S. (Vice-President) (Director of Scientific Research, Air Ministry).

Lieut.-Colonel M. F. Scanlon (Assistant Military Attaché for Aviation, American Embassy).

Lord Sempill, A.F.C., F.R.Ae.S. (Past-President).

Mr. H. O Short, F.R.Ae.S. (Managing Director, Short Brothers, Ltd.).

Professor R. V. Southwell, M.A., F.R.S., M.I.Mech.E., F.R.Ae.S. (Engineering Laboratory, Oxford).

Sir Henry Tizard, K.C.B., C.B., A.F.C., F.R.S., F.R.Ae.S. (Rector of Imperial College of Science and Technology) (Chairman of the Aeronautical Research Committee).

ABSTRACTS FROM THE SCIENTIFIC AND TECHNICAL PRESS.

Issued by the

Directorates of Scientific Research and Technical Development, Air Ministry.

(Prepared by R.T.P.)

No. 60. October, 1938.

Multiplicity in Armament Types. (C. Rougeron, Rev. de l'Arm. de l'Air, No. 102, January, 1938, pp. 40-58. In course of translation.) (60/1 France.)

The author issues a powerful plea against reduction in armament types by over-standardisation. In order to be reasonably effective, the standardised equipment generally entails special materials and methods of manufacture which may lead to difficulties in case of an emergency. As an example, prior to 1914 the French authorities had standardised the single explosive " melinite " for practically all purposes. As a result there soon occurred a serious crisis in the munition supply, since the basis of melinite—toluol—was not available in sufficient quantity. The industrial resources of a country can only be utilised fully by employing a variety of armaments each carefully chosen for a specific purpose.

A case in point is the all-metal construction of aircraft. In this case production is tied down to large specialised plants extremely vulnerable to air attack. The same dangers do not apply when wood is used as an aircraft material. Another advantage of alternative types of armament lies in the fact that the method of attack can be varied and the defence rendered more difficult.

Aircraft v. Battleship. (P. Etienne, Rev. de l'Arm. de l'Air, No. 102, January, 1938, pp. 59-66.) (60/2 France.)

An interesting discussion has been going on in the French Technical Press on the possibilities of the battleship resisting successfully an aircraft attack. In his well-known book entitled " Bombing Aviation," Rougeron favours the chance of the aircraft. Naval experts, however, point out that the proposed methods of aerial attack are complicated and that if the ships are dispersed and provided with modern A.A. artillery, the chances of the aircraft are very small. Recent experiences in the Spanish war indicate, however, that ships are by no means invulnerable, and that dive bombing attacks can be carried out so quickly that even a trained crew has not sufficient time to fire its guns (attack on German battleship " Deutschland "). At the same time the frequent air raids on Spanish harbours demonstrate the extreme vulnerability of targets of this type.

From all the above we may conclude that aircraft in a future naval war will scarcely be used to bear the brunt of the first attack on an enemy fleet at sea, but will act in co-operation with surface ships, intervening effectively as soon as the enemy shows signs of disorganisation.

Coastal bases, on the other hand, will form a most promising aerial target for independent aerial attack.

The Fighting Aeroplane—Will Multi-Seater Combat Planes Challenge the "Flying Fortress?" (H. J. Alter, Army Ord., Vol. 19, No. 110, Sept.-Oct., 1938, pp. 79-84.) (60/3 U.S.A.)

The author is of the opinion that only combat planes of the type Bell XMF-1 will be able to operate against large bombers such as the Boeing XB-15.

The principal reasons for preferring the combat plane (crew of 6-7) to the single or 2-seat fighter are the following:—

(1) The combat plane is capable of sustained fighting at all times and under varied conditions.
(2) Large bore weapons can be carried without serious effects on structure or performance.
(3) Heavy concentration of fire.
(4) Capable of fighting at high altitudes.
(5) The large crew render the machine effective even if casualties occur.

4 photographs.

Aircraft Display at the Nuremberg Rally. (Les Ailes, No. 901, 22/9/38, p. 5.) (60/4 Germany.)

The following aircraft were specially noted:—

Dornier Bombers.
Messerschmitt Fighters (Me 109).
Junkers Dive Bombers Ju 87.
Messerschmitt Twin-engine Fighter (Me 110) fitted with 2 cannons and 4 machine guns.
Focke Wulf Twin Fuselage Aircraft.
Twin-engined Siebl-Halle Trainer.
Reconnaissance Aircraft of various types about which no further particulars are available.

Spanish Civil War—Franco's Claims as to Losses Inflicted on the Government Air Force. (Aeroplane, Vol. 55, No. 1,428, 5/10/38, p. 407.) (60/5 Great Britain.)

The following table gives a list of aircraft shot down, according to official figures supplied by Franco's government.

Type	Year		Total
	1937	1938	
Martin Bombers (Russian built) ...	12	80	92
Natachas (biplane)	1	28	29
Ratas (Boeing)	7	111	118
Curtiss (Mosca)	41	308	349
Potez	20	0	20
Vickers	10	0	10
Dewoitine	13	0	13
Dornier (Boat)	5	1	6
Savoia (Seaplane)	11	0	11
Breguet	25	0	25
Nieuport	33	0	33
Praga	0	4	4
Faix	0	1	1
Unidentified	180	133	313

Of interest is the rapid increase in Russian types during 1938. Apparently only few French machines can have been used by the Spanish government during the same period.

Formulation of the Resistance Laws of Projectiles. (H. Herrmann, W.T.M., Vol. 42, No. 9, Sept., 1938, pp. 397-411.) (60/6 Germany.)

The resistance laws for projectiles are suitably expressed in the forms $f(v)=C_n V^n$ or $K(v)=f(v)/V^2$, where C_n, n and k are functions of the velocity. It is convenient to express the results in terms of velocity zones over which C_n, n and k are constant. The values of these constants are chosen so that the curves are continuous (*i.e.*, $f(v)$ at end of one zone $=f(v)$ at the beginning of the next). At the point of junction, however, a change of slope necessarily occurs.

The following is an example of such a method of representation :—

Zone.	V (m./sec.).	$10^y C_n$	N.
I	0-240	1.4×10^{-2}	2
II	270-295	0.58×10^{-4}	3
III	295-375	0.67×10^{-9}	5
IV	375-419	0.94×10^{-4}	3
V	419-550	0.39×10^{-1}	2
VI	550-800	0.26	1.7
VII	800-1000	0.71	1.55

Only two points in each zone can agree exactly with the experimental resistance law and when integrating trajectories it may be necessary to utilise different zone sub-divisions for the beginning and end of the trajectory. The author shows how this can be done in a simple manner with the help of logarithmic plotting.

The "Oerlikon" Cannon Mounting for Aircraft. (O. B. Server, W.T.M., Vol. 42, No. 9, September, 1938, pp. 411-415.) (60/7 Germany.)

A novel form of gun ring for the Oerlikon cannon F.F.S. 20 mm. calibre is described and illustrated.

The azimuth and elevation of the cannon are controlled by oil pressure, the locking and firing of the gun being carried out by compressed air.

The oil pressure for the oil servo-motor is provided off a special oil pump driven electrically from the aircraft supply system, and the compressed air is supplied from a pressure bottle.

The gun is pointed by a single control lever possessing freedom of motion in two directions. Movement to the left or right causes a corresponding turning of the gun whilst an up and down motion of the lever changes the elevation. The two motions can obviously be combined, the maximum angular velocity in either direction being of the order of 30°/second. The control lever is fitted with a push button for series fire, but single shots can also be fired. The limits in elevation are $-10°$ to $+90°$, whilst the full 360° are available for azimuth.

The gun mounting is provided with a modern optical sight, compensated for air speeds up to 450 km./hour.

The complete weight of the mounting (without gun) is 95 kg.

French Views on the Employment of Army Co-operation Machines. (A. Ehrhardt, Luftwehr, Vol. 5, No. 8, August, 1938, pp. 312-313.) (60/8 France.)

Up to quite recently, the duties of army co-operation could be classified under the following heads :—

(1) Observation of battle front from a relatively low altitude (500-600 m.).
(2) Ground attack (bombs and machine guns).
(3) Communication with advanced posts.

Experience in Spain has shown that when exposed to modern A.A. artillery ground observation can no longer be carried out from altitudes of the order of 500 m. In future such flights have to be made at high altitude (relying on a specially trained observer) alternating with high speed dives to within a few feet of the ground. Such dives are carried out whenever detailed information is

required and are very successful in spite of the high aircraft speed, provided the information required is sufficiently simple, *e.g.*, is wood Z occupied by the enemy —have our advanced forces reached X—why is regiment Y not advancing, etc. After the dive the aircraft climbs as rapidly as possible so as to get outside the effective range of the A.A. artillery.

The low flying technique, once acquired, renders wireless unnecessary, since it is quite easy to drop a message.

In the opinion of the French author, it is essential that this new form of army co-operation be thoroughly practised in peace time so that the infantry can get used to this method of warfare.

Balloon Barrages. Based on an article in Bulletin Belge des Sciences Militaires, April, 1938. (Luftwehr, Vol. 5, No. 8, August, 1938, pp. 332-336.) (60/9 Belgium.)

Balloon barrages were first employed by the Italians for the protection of Venice in 1916. The balloons were spherical and operated at very moderate altitudes (2,000 m.).

The spherical shape has no dynamic stability and can therefore only be used in the absence of wind. (The Venice region is calm for 25 days of the month.) For general use only the kite balloon (streamlined) can be considered. The author favours the type in which the envelope expands as the balloon ascends. The French " Ariel " balloon is of this kind, having a volume of 400 m.^{3} on the ground and 700 m.^{3} at the ceiling (app. 6,000 m.).

The balloon structure is composed of six lobes which are held together by elastic bands. On the ground the shape is roughly hexagonal, the extra volume at altitude being produced by expansion of the lobes attached to the corners of the hexagon. The article concludes with some remarks on the distribution of the balloon barrage so as to give protection to a variety of possible targets.

The Effect of Projectiles and Bombs on Concrete. (J. Ruziaka, with comments by M. Schweninger, Z.g.S.S., Vol. 33, No. 5, May, 1938, pp. 141-142.) (60/10 Czecho-Slovakia.)

The author assumes that penetration of the concrete occurs before the bomb explodes. The depth of penetration h is given by

$$h = E/(\pi D^2 \,.\, W/4)$$

where E = kinetic energy in kg.-metres.
D = diameter of bomb in cm.
W = average resistance of material in cm. kg./cm.^{3}.

In the case of ferro-concrete $W = 1{,}500 - 2{,}000$. The radius of destruction R is given by

$$R = \sqrt[3]{(N/p \,.\, t)}$$

where N = quantity of explosive in kg.
p = a material coefficient.
t = an explosion density coefficient depending on depth of penetration.

p and t are given in the form of curves.

The author concludes that only one-third of the explosive charge is effective in demolishing the concrete if the bomb does not penetrate more than two calibre lengths.

Effective protection can only be provided by high grade concrete with three dimensional iron reinforcement. Uniform strength throughout the thickness is essential to prevent the concrete peeling off in layers.

The Effect of Cavitation on the Operation of the Voith-Schneider Propeller. (H. Mueller, Z.V.D.I., 14/5/38, pp. 566-8. Eng. Absts., Vol. I, No. 8, Section 2, Aug., 1938, p. 126.) (60/11 Germany.)

In this propeller a series of suspended vertical blades of aerofoil section rotate about a vertical axis, and during the revolution each blade is caused to rotate about its own axis in such a way as to present the proper incident angle throughout the revolution. By an alteration in the blade-gear the propeller can be caused to exert a sideways " steering " force instead of the normal forward thrust. Experiments were made on a propeller 8in. diameter with blades 5in. long, in a channel 27in. wide and 10in. deep. The torque applied was measured by the reaction of the driving motor against a spring, and the thrust was measured with a spring-balance, the propeller and motor being hung on wires. The motor and measuring gear were mounted in a chamber which could be evacuated down to a head of -32.8ft. of water. The results indicate that for forward motion or steering-angles of less than 15 degrees the loss due to cavitation at high speeds does not exceed 10 per cent. With larger steering-angles the limited size of the channel influenced the results, and it was necessary to obtain the blade-forces graphically. The calculations indicated that for 90 degrees steering-angle cavitation began to influence the efficiency only at a speed of 20 knots, and that at 40 knots it caused a 50 per cent. reduction.

The Resistance of Aircraft Radiators Taking into Account the Warming Up of the Air (Comparison of Theory and Experiment). (B. Gothert, L.F.F., Vol. 15, No. 9, 10/9/38, pp. 427-44.) (60/12 Germany.)

The general question of radiator resistance is investigated theoretically for a cowled radiator both when isolated and when placed in close proximity to the aircraft (tunnel installation). The differences arising when heat transfer takes place are discussed and the results compared with practical experiments. Although theoretically the tunnel installation with heat transfer may have a negative drag (*i.e.*, exert a propulsive effort), the experiments show that so far pronounced interference effects cannot be avoided, the resistance of the cowled radiator on the aircraft being considerably greater than when working in a free air stream. Further experiments on various types of installations are urgently needed.

The Minimum Resistance of High Speed Aircraft. (H. Eick, L.F.F., Vol. 15, No. 9, September, 1938, pp. 445-62.) (60/13 Germany.)

It is important to know how far the drag of modern high speed aircraft can be reduced and estimate the possible increased performance of such an ideal aircraft. The author describes a method of determining the minimum resistance rapidly. The main dimensions of the aircraft are retained, but elliptic lift distribution is assumed, the shape is streamline, there is no break away of the flow and the surface is perfectly smooth.

In addition the author considers the effect of the thickness of the various exposed structural parts as well as the radiator resistance. The ratio of the minimum resistance to the actual resistance of the aircraft in flight is called the aerodynamic efficiency of the aircraft. This factor was calculated for a number of modern high speed aircraft (1937). It appears that an aerodynamic efficiency of 50 per cent. can be realised at the moment. If this could be raised to 75 per cent. (a value realised on complete models tested in the large D.V.L. tunnel) an increase in maximum speed of the order of 10 per cent. would result.

Calculation of the Downwash Behind Wings. (H. Multhopp, L.F.F., Vol. 15, No. 9, 10/9/38, pp. 463-7.) (60/14 Germany.)

Investigations on the rolling-up process of the vortex sheet behind the wing have shown that this process has only a slight effect on the flow at the tail surfaces.

The downwash is therefore calculated in the neighbourhood of the sheet with the help of a Taylor expansion without taking into account the break-up of the sheet.

A qualitative examination of the pertinent factors shows that for a small downwash wing taper should be avoided (the chord kept as uniform as possible).

At large angles of incidence, the downwash is controlled mainly by the break away of the flow at the wing and this renders prediction difficult. The wing roots also exert a powerful influence. An examination of swept-back wings (arrow formation) showed a complete reversal of the downwash with increase in angle of incidence.

Flight Tests and Flying Qualities of Zah 1—25 Aircraft. (V. S. Vedrov, Aeronautical Engineering, U.S.S.R., No. 1, January, 1938, pp. 9-24. Translation available.) (60/15 U.S.S.R.)

The aerodynamic characteristics of the aircraft are described and some particulars of the flight tests carried out before the long distance record was attempted are given.

The main difficulty of the tests consisted in the fact that they had to be carried out at an average flying weight of 5 tons, whilst for the record the all-up weight was approximately 12 tons. The large extrapolation necessitated great accuracy in the measurements as well as a sound basis for the calculations. The article shows that under the favourable meteorological conditions existing during the polar flight the actual range was well within the capacity of this type of aircraft. The criticism published in a British Trade journal to the effect that an intermediate landing must have been made is met by pointing out an error in the British calculations. The fuel consumption depends on the weight of the aircraft and instead of basing the possible range on the starting weight (as was done in the criticism) a better estimate is obtained by taking the average weight during the flight.

Wind Tunnel Investigation of Rectangular and Tapered N.A.C.A. 23012 Wings with Plain Ailerons and Full-Span Split Flaps. (C. J. Wenzinger and M. B. Ames, N.A.C.A. Tech. Note No. 661, August, 1938.) (60/16 U.S.A.)

An investigation was made in the N.A.C.A. 7- by 10-ft wind tunnel to determine the aerodynamic properties of rectangular and tapered N.A.C.A. 23012 wings with plain ailerons and a full-span split flap, the flap retracting ahead of the ailerons. Measurements were made of lift and drag and of pitching, rolling, yawing, and hinge moments for all conditions of full-span flaps neutral and deflected at different chord locations.

The results of the tests showed that a $0.20c_w$ full-span split flap located at approximately the $0.75c_w$ point gave higher lift coefficients than had previously been obtained with a conventional $0.20c_w$ partial-span split flap of a length to permit satisfactory control with plain ailerons. Still higher lifts were obtained if the full-span flap, when deflected, was moved back to the aileron axis. Moving the flap back to the aileron axis, in general, improved the aileron characteristics over those with the flap retracted. The most promising arrangement of full-span split flap and plain aileron combination tested, both for high lift and lateral control, was the rectangular wing with $0.20c_w$ flap deflected 60° at the $0.90c_w$ location with $0.10c_w$ semispan ailerons.

The Experimental and Calculated Characteristics of 22 Tapered Wings. (R. F. Anderson, N.A.C.A. Report No. 627, 1938.) (60/17 U.S.A.)

The experimental and calculated aerodynamic characteristics of 22 tapered wings are compared, using tests made in the variable-density wind tunnel. The wings had aspect ratios from 6 to 12 and taper ratios from 1.6:1 to 5:1. The compared characteristics are the pitching moment, the aerodynamic-centre po. ition, the lift-

curve slope, the maximum lift coefficient, and the curves of drag. The method of obtaining the calculated values is based on the use of wing theory and experimentally determined aerofoil section data. In general, the experimental and calculated characteristics are in sufficiently good agreement that the method may be applied to many problems of aeroplane design.

The Present Status of Airship Construction, Especially of Airship Framing Construction. (H. Ebner, Z.F.M., Vol. 24, Nos. 11 and 12, 6 and 22/6/33. Available as Translation T.M. No. 872.) (60/18 Germany.)

The author discusses, in broad outline, the status of airship construction in the various countries, at a time when commerce over great distances might be finally opened up to the airship through the performances of the "Graf Zeppelin." After a short historical review, a survey of the most important rigid and semi-rigid airships built since 1925, their differences and special problems, is made. In more detailed treatment, the framing construction of the more recent rigid airships and some especially interesting structural questions are investigated. An extensive bibliography (39 items) is given.

The Effects of Partial-Span Plain Flaps on the Aerodynamic Characteristics of a Rectangular and a Tapered Clark Y Wing. (R. O. House, N.A.C.A. Tech. Note No. 663, Sept., 1938.) (60/19 U.S.A.)

An investigation was made in the N.A.C.A. 7- by 10-ft wind tunnel to determine the aerodynamic characteristics of tapered and rectangular wings with partial-span plain flaps. Two Clark Y aerofoils equipped with centre-section and with tip-section flaps were tested.

The results showed that the aerodynamic characteristics of partial-span plain flaps were, in general, similar to those of split flaps of the same span, but that the lift and the drag were less for the wing with plain flaps than for the wing with split flaps of comparable size. For the rectangular wing with centre-section plain flaps, the maximum lift and the lift-drag ratio at maximum lift were greater and the drag at maximum lift was less than for the wing with tip-section plain flaps of the same size. The maximum lift of the tapered wing varied in the same manner as that of the rectangular wing but the drag and the lift-drag-ratio relationships were opposite.

Analytical Comparison of Helicopter and Aeroplane in Level Flight. (M. Knight, J. Aeron. Sci., Vol. 5, No. 11, Sept., 1938, pp. 431-5.) (60/20 U.S.A.)

The general power equation is obtained for the helicopter rotor in level flight on the assumption that the circulation about the rotor blades is independent of radius and forward velocity.

The power required by the rotor is then compared with that required by a wing whose span is equal to the rotor diameter. Curves are given showing the variation of this power ratio with forward speed for three different rotor solidities and for a wing of aspect ratio 6, both for the lifting surfaces only and for the complete helicopter and aeroplane.

The analysis indicates the superiority of the helicopter rotor over the aeroplane wing at high speeds and its inferiority in the climbing range.

Range and Take-off Calculations for Plane with Continuously Controllable Pitch Propellers. (A. B. Scoles and W. A. Schoech, J. Aeron. Sci., Vol. 5, No. 11, September, 1938, pp. 436/441.) (60/21 U.S.A.)

A method is developed for evaluating the ultimate range parameter in miles per pound of fuel consumed for planes equipped with continuously controllable pitch propellers. The method is then applied to investigate the effect of several

geometrical parameters of the aircraft on the range. It appears that an increase in maximum range with increased wing loading may generally be expected and in general there will be an optimum combination of aspect ratio and span for a given wing loading. The gain in range associated with increased wing loading will, however, be small for loadings in excess of 50 lb. per sq. ft.

The authors also investigated the effect of various parameters on length of take-off for land and sea planes. It appears that increasing power to gain a better take-off invariably reduces the maximum range considerably with no gain in cruising speed. If increased speed is needed for express services, the penalty must be paid in payload.

The take-off characteristics of large long range sea or land planes do not differ very much, but in some cases the sea plane will have the advantage. (Five references.)

Performance Calculations on the Koken Long-Range Monoplane. (H. Kimura, Aer. Res. Inst., Tokio, Report No. 166, August, 1938, pp. 300-85.) (60/22 Japan.)

The performance of the Koken Long-Range Monoplane, when fitted with the " SW-1 " wooden propeller, was calculated over the range of total weight from 5,000 kg. to 9,500 kg. This monoplane set up the world's distance record of 11,651 km. over a closed circuit, and at the same time the international speed record of 186 km./h. over 10,000 km. in May, 1938.

The principal characteristics and the calculated performance of the monoplane are as follows:—

Number of crew	2 or 3
Span	27.93 m.
Length overall	15.06 m.
Height overall	3.84 m.
Wing area	87.3 m^2.
Empty weight with fixed equipment ...	4,225 kg.
Loaded weight	9,200-9,500 kg.
Total capacity of fuel tanks	7,500 l.

Performance:

Total weight (kg.)	5,000	9,500
Wing loading (kg./$m.^2$)	57.3	108.8
Power loading (kg./H.P.)	6.25	11.9
Wing power (H.P./$m.^2$)	9.16	9.16
Maximum speed at sea level (km./h.)	250	243
Cruising speed at 2,000 m. at 75 per cent. power (km./h.)	247	233
Economical speed at 2,000 (km./h.)	155	208
Stalling speed (km./h.)	96	132
Initial rate of climb (m./s.)	6.06	2.10
Climb to 2,000 m. (min.-sec.)	6-31	23-55
Service ceiling (m.)	7,310	2,900
Kilometres per kilogram of fuel at 2,000 m. (km.)	3.86	2.26
Range at 2,000 m. (km.)	—	13,550
Duration at 2,000 m. (h.)	—	75
Take-off run on concrete runway (m.)	250	1,250

The flight tests were in satisfactory agreement with prediction and the comparison will form the subject of the subsequent report.

Civil Aviation—Statistical and Technical Review for 1937. (The Engineer, Vol. 166, No. 4317, 7/10/38, p. 379.) (60/23 Great Britain.)

The regularly operated air routes throughout the world cover 334,000 miles, the total distance flown in 1937 being of the order of 200 million miles. One sixth of this total distance applies to traffic in the British Empire.

Compared with 1936, the number of flights carried out by British aircraft is practically unaltered, whilst the Dutch, French and German flight increased by 34 per cent., 25 per cent., and 57 per cent. respectively. During the year there were 47 accidents involving aircraft registered in the United Kingdom. (60 in 1936.)

The majority of the accidents (15 fatal and 7 serious) occurred in private flying. Racing and exhibition flying only accounted for 2 accidents.

Two-Dimensional Model Experiments on the Non-Steady Scavenging Process in Two-Stroke Engines. (F. Schultz-Grunow, Forschung, Vol. 9, No. 5, Sept.-Oct., 1938, pp. 235-241.) (60/24 Germany.)

The experiments were carried out using a rectangular water channel fitted with inlet and exit passages to correspond to the engine ports. A flat piston reciprocates in the tank and the motion of the water is recorded photographically by means of aluminium powder sprinkled on the surface. Examples of such photographs are given. Changes in the level of the water are recorded electrically by means of immersed wires.

Provided the changes in level are small, the flow of a gas follows similar laws and there exists also analogy between the propagation of a sound wave and that of a surface surge.

The necessary conditions of similarity are stated mathematically and it is shown how the results obtained can be applied to the engine under certain conditions.

Experiments are in hand to extend the method to three dimensional investigations.

Drop in Thermodynamic Efficiency Due to High Piston Speeds. (E. Justi and M. Kohler, Forschung, Vol. 9, No. 5, Sept.-Oct., 1938, pp. 242-251.) (60/25 Germany.)

The authors point out that in high speed piston engines, the pressure on the piston is not the same as that recorded by a stationary manometer.

Using the Kinetic theory the differences can be calculated in any special case, since it depends on the ratio of the molecular speed to the piston speed. As a result of the finite molecular speed, the pressure on the piston is raised during compression and lowered during expansion, the resultant drop in efficiency amounting to as much as 10 per cent. for a spark ignition engine having a maximum piston speed of the order of 20 m./sec.

Comparison of Ideal and Actual Combustion Temperatures and Pressures. (G. von Elbe and B. Lewis, Chemical Reviews, Vol. 21, December, 1937. pp. 413-420. Fuel, Vol. 17, No. 9, September, 1938, pp. 284-5.) (60/26.)

In moist hydrogen-oxygen mixtures diluted with argon, helium, or excess hydrogen, explosion pressures are found that agree with the theoretical pressures calculated from band spectroscopic data. In dry mixtures the observed pressures are lower, possibly due to heat loss by luminescence radiation. In moist mixtures diluted with nitrogen or excess oxygen the pressures are higher. This has been ascribed to the time-dependence of specific heats, called excitation lag. This excitation lag has been linked to gas vibrations which appear early in the explosion. The results with carbon monoxide-oxygen and with acetylene-oxygen mixtures can also be interpreted by heat loss and excitation lag. If a small amount of hydrogen is added to CO-O_2 mixtures the heat loss appears to be reduced

considerably, probably due to the shorter duration of the explosion. Excellent agreement is found between experimental and theoretical explosion pressures in ozone-oxygen explosions. An explanation of the absence of excitation lag in the latter is proposed. Measurements of expansion ratios in soap bubble explosions of carbon monoxide-oxygen mixtures and flame temperatures by the line-reversal method of coal gas-air mixtures show a behaviour similar to explosion pressures in hydrogen-oxygen and carbon monoxide-oxygen mixtures.

Measured Feed Lubrication. (Oil Engine, Sept., 1938, pp. 158-9. Metropolitan Vickers Tech. News Bulletin, No. 627, 23/9/38, p. 8.) (60/27 Great Britain.)

For engine parts requiring a rate of oil lubrication depending on speed, such as the cylinder wall of an oil engine, some sort of mechanical lubricator becomes necessary. In this article details are given of the methods of drive and pump action of Wakefield, T and K, Delvac and Bosch lubricators. All the above makes are of the multiple unit type enabling different parts of an engine to be supplied at varying rates of oil feed with, in some cases, different grades of oil. Illustrated with three photographs and three diagrams.

Reaction Chains in the Thermal Decomposition of Hydrocarbons—A Comparison of Methane, Ethane, Propane and Hexane. (J. E. Hobbs and C. N. Hinshelwood, Proc. Roy. Soc., Series A, Vol. 167, No. 931, 23/9/38, pp. 447-55.) (60/28 Great Britain.)

A comparison has been made of the inhibition by nitric oxide of the thermal decomposition of methane, ethane, propane and hexane. The mean chain length, as defined by the ratio of the rates of the uninhibited and fully inhibited reactions, shows no marked variation as the series is ascended, has values from 2 to 15 according to conditions, and, for a given hydro-carbon, decreases as the initial pressure increases. The curves showing the decrease in rate as a function of nitric oxide concentration can be expressed in terms of a simple theory of chain breaking. The mean chain length depends upon the relative values of three activation energies, namely those of radicle formation, of decomposition by internal rearrangement, and of chain propagation. Approximate evaluation of the last shows that it tends to decrease with the higher hydrocarbons.

A Study of Chain Reaction in the Thermal Decomposition of Diethyl Ether. (J. E. Hobbs, Proc. Roy. Soc., Series A, Vol. 167, No. 931, 23/9/38, pp. 456-63.) (60/29 Great Britain.)

The course of the curves showing the rate of decomposition of diethyl ether as a function of minute additions of nitric oxide is independent of the concentration of diethyl ether. The removal of a radicle must thus be in competition with some reaction the rate of which is entirely independent of the ether concentration. This must be a unimolecular dissociation of the radicle itself. This is in contrast to the inhibition of the decomposition of ethane where the nitric oxide removes a radicle which otherwise would have reacted with an ethane molecule. A chain mechanism explaining these results is the same as that put forward by Rice and Herzfeld (1934) to explain the first order nature of the reaction. This mechanism gives an expression for the shape of the " inhibition curve " and accounts for the variation of the mean chain length with the ether pressure. From the amount of nitric oxide required for a given degree of inhibition the average life of the radicle can be calculated to be of the order of 1.2×10^{-6} sec.

Measurement of Oil Pressure in Bearings. (Forschung, Vol. 9, No. 5, Sept.-Oct., 1938, p. 256-7.) (60/30 Germany.)

The D.V.L. have developed a pressure indicator suitable for recording oil pressures in bearings. The instrument consists of a small piston (1 mm. diameter,

weight .16 gm.) which is flush with the bearing surface when loaded by an external oil pressure in excess of the film pressure. If the film pressure exceeds the external load, the piston rises a fraction of a mm. and lights up a neon lamp. The length of time the lamp lights is recorded on a drum rotating at journal speed (abscissæ) whilst the back pressure controls the ordinates. As many as 22 of these recorders were distributed over the bearing, tests being run both with steady and pulsating bearing loads. In the latter case the journal undergoes periodic displacements inside the bearing with corresponding changes in the oil pressure distribution. If the load is increased so that semi fluid friction is operative, the maximum film pressure is displaced in a direction opposed to the rotation of the journal. This is because the increased bearing friction causes the journal to move in this direction, thus displacing the position of minimum clearance (maximum film pressure).

Theoretical Investigations and Experiments on Ignition Lag and Knock. (F. A. F. Schmidt, Forschungsheft, No. 392, Sept.-Oct., 1938, pp. 1-14.) (60/31 Germany.)

The paper presents an extension of previous work carried out by the author and published in L.F.F. Vol. 14 (1937) p. 640. (This paper is available as Air Ministry Translation No. 727.)

The author concludes that the characteristics of a fuel cannot be stated in terms of a single constant (such as octane or cetene number) but that at least two and generally three constants are required.

Thus no correlation between knock ratings can be expected if in one set of tests the charge temperature was varied whilst in the other the charge pressure.

For this reason the author favours knock rating being based on an equation characterising the ignition lag of the fuel as a function of temperature and pressure of the charge. (Thirty-three references.)

The Ignition Lag in Diesel Engines. (H. H. Wolfer, Forschungsheft, No. 392, September-October, 1938, pp. 15-24.) (60/32 Germany.)

The influence of various factors on the ignition lag was investigated by means of experiments carried out in bombs. Certain of the conclusions were verified by engine experiments. It appears that the ignition lag depends primarily on the temperature and pressure of the combustion air and is very little affected by:—

(1) Excess air coefficient
(3) Shape of combustion chamber
(3) Type of injection nozzle
(4) Value of injection pressure
(5) Amount of air turbulence
(6) Temperature of fuel (provided the latter does not exceed 100° C.)

The type of function connecting pressure and temperature in the expression for ignition lag indicates that the chemical reactions are of the chain type.

Electrically Welded Joints. (A. L. Hale, Welding Industry, September, 1938, pp. 269-75. Metropolitan Tech. News Bulletin, No. 626, 16/9/38, p. 5.) (60/33 Great Britain.)

Concluding a study of the direct stresses in welds which take a definite share of the external loading, the author considers welds subjected to longitudinal shear. The various factors involved are made clearer by reference to a simple analogy utilising two spiral springs. Turning to the question of residual stresses in welds and their combination with stresses produced by external loads, the writer examines the condition of stress on a plane at right angles to the direction of a butt weld. The tensile stresses in the weld and compressive stresses in the parent metal are shown to develop during cooling. Illustrated with 15 diagrams.

Damping of Torsional Vibrations by Liquid Couplings. (F. Sochting, Z.V.D.I., Vol. 82, 4/6/38, pp. 701-3. Eng. Absts., Vol. 1, No. 7, Section 3, Aug., 1938, p. 114.) (60/34 Germany.)

With the object of reducing vibrations resulting from impacts and sudden large variations in power, frictional or liquid or elastic couplings are sometimes introduced between prime movers and driven machines. In this way variations in speed are minimised. The paper discusses, from a mathematical standpoint, the effect of the liquid couplings frequently introduced between load and motors, or in association with gearing. A suitable damper can be designed for every condition of coupling and speed; only when the excited frequency in the coupling is equal to that introduced by the impact can the coupling act as though solid. In such a case vibration will continue; otherwise, and in general, it fades out. Even a small difference between the introduced and the natural frequency is sufficient, and care must be taken in designing the shaft, that the size is suitable. In practical applications the results are much more favourable than might be expected theoretically, on account of the many other damping influences present in the machine, such as bearing friction, which cannot be taken into account. An important conclusion is that liquid couplings cannot themselves excite vibrations.

An Entirely New Method of Surface Finishing. (Part II.) (W. F. Sherman, Iron Age, 8/9/38, pp. 40-5. Metropolitan Vickers Tech. News Bulletin, No. 627, 23/9/38.) (60/35 Great Britain.)

In the second part of this series, the author presents some fundamental new conceptions and definitions of terms relating to "Superfinishing." Numerous charts summarise the experience of Chrysler Corp. in the use of this technique as compared with conventional methods of finishing engine parts. The process calls for careful analysis and special machines which enable pieces such as tappets and valve stems to be "Superfinished" quickly with a low rate of stone wear. Illustrated with three photographs, six diagrams and two tables.

Bearing Metals. (K. O. Hodgson, Power Transmission, 15/9/38, pp. 471-7. Metropolitan Vickers Tech. News Bulletin, No. 627, 23/9/38, p. 7.) (60/36 Great Britain.)

It is pointed out that of the many principal properties given as being desirable in a bearing metal, the most important seem to be, high fatigue resistance, good bonding, the eutectic temperature as compared with the working temperature, lack of segregation, coefficient of expansion, and pressure resisting properties. Turning to the types of alloys used as bearing metals, the author analyses their characteristics in the light of requirements previously outlined. Illustrated with seven photo-micrographs.

Researches on the Properties of Heat Resisting Alloys Used in Internal Combustion Engines. (F. Bollenrath, H. Cornelius and W. Bungardt, L.F.F., Vol. 15, No. 9, 10/9/38.) (60/37 Germany.)

The article is mainly concerned with the blade material of single stage exhaust driven turbines.

Up to temperatures of the order of 600° C., the following austenitic alloys are available:—

Cr-Ni-Ti-Fe
Fe-Cr-Ni-Ta-Nb-Tu (or Mo).
Cr-Ni-Co-Fe-Tu-Mo
Cr-Ni-Co-Fe-Tu-Mo (with additions of Ta, Nb, Ti).
Fe-Cr-Ni-Tu-Ti

An important factor is the density of the material at high temperatures. This was calculated from the room density and the expansion coefficients.

Temperature stability was investigated by subjecting sample blades to alternate heating and cooling and noting the number of cycles before either deformation or surface cracks appeared. Tensile tests and micro structure carried out subsequently completed the investigation. It appears that no material suitable for blade temperature in excess of 700°C. is at present available.

Behaviour of a Plate Strip Under Shear and Compressive Stresses Beyond the Buckling Limit. (L.F.F., Vol. 14, No. 12, 20/12/37, pp. 627-39. Available as Translation T.M. 870.) (60/38 Germany.)

The present report is an extension of previous theoretical investigations on the elastic behaviour of a plate under compression and shear in the region above the critical. The main object is the clarification of the behaviour immediately above the buckling limit since no theoretical expressions for this range have so far been found and since experimentally, too, any degree of regularity in the behaviour of the plate in the range between the critical load and about three to four times the critical, is discernible only with difficulty. The present report thus supplements, for example, the experimental investigations of Lahde and Wagner.

The Crinkling Strength and the Bending Strength of Aircraft Tubing. (W. R. Osgood, N.A.C.A. Report No. 632, 1938.) (60/39 U.S.A.)

The upper limit of the column strength of structural members composed of thin material is the maximum axial stress such members can carry when short enough to fail locally, by crinkling. This stress is a function of the mechanical properties of the material and of the geometrical shape of the cross section. The bending strength of structural members, as measured by the modulus of rupture, is also a function of these same variables. Tests were made of round tubes of chromium-molybdenum steel and of duralumin to determine the crinkling strengths and the bending strengths in terms of the specified yield strength and the ratio of diameter to thickness. Empirical formulæ are given relating these quantities.

Flat Plates Under Pressure. (E. Moness, J. Aeron. Sci., Vol. 5, No. 11, September, 1938, pp. 421-5.) (60/40 U.S.A.)

Curves and equations are given for the maximum deflection and stress in rectangular sheets under pressures encountered in aeroplane practice. The object of this paper is to supply the designer of high altitude aeroplanes with systematic information for the design of thin sheets which have to withstand a given pressure differential. A " thick " plate resists loads only by bending; its middle surface does not stretch; its deflection is negligible compared to its thickness. A " very thin " plate has no bending strength; it resists loads entirely by tension; its middle surface stretches; its deflection under load is so large that the thickness becomes negligible compared to it. The " thin " plate resists load both by bending and tension; its deflection is of the same order as its thickness. A plate of given dimensions does not always belong to the same category. A " thick " plate will become a " thin " one if the load applied to it is sufficiently large to cause it to deflect several times the thickness; similarly, a " thin " plate will behave as a " very thin " one under large loads. For the underlying theory for the equations given, reference is made to the work of A. and L. Foppl.*

Stainless Steel in Aircraft. (H. V. Thaden, J. Aeron. Sci., Vol. 5, No. 11, September, 1938, pp. 447-454.) (60/41 U.S.A.)

Stainless steel for aircraft construction offers the following advantages:—

(1) Favourable strength—weight ratio,

(2) Superior corrosion resistance,

* Foppl, August and Ludwig. Drang und Zwang. Vol. I, R. Oldenburg, Munchen und Berlin, 1924.

(3) Spot welding gives smooth surface and reduces cost,
(4) Lower maintenance charges. (No surface treatment required, small likelihood of surface scratches affecting performance.)

It is generally conceded that a successful aircraft must necessarily be a compromise in design and material. Although no one type of material can be the complete answer to all problems, the author is of the opinion that the use of stainless steel in aircraft construction will predominate in the future.

Damping of Forced Vibrations by Coupled Systems. (E. Lehr and A. Weigand, Forschung, Vol. 9, No. 5, September-October, 1938, pp. 219-228.) (60/42 Germany.)

Coupled inertia masses are very efficient for absorbing vibrations. So far torsional vibration dampers have only rarely been designed on this principle, probably because the necessary calculations appeared difficult. The authors describe a simple method for determining the characteristics of the coupled system required to meet certain conditions and apply the method to a worked-out example.

Modern Extensometers. (A. Thum, O. Stenson and H. Weiss, Forschung, Vol. 9, No. 5, September-October, 1938, pp. 229-234.) (60/43 Germany.)

After briefly reviewing the static and dynamic extensometers at present in use, the authors describe a new instrument which utilises an electromagnetic recording system. In this instrument (known as M.P.A.) the extension moves a diaphragm which, in its turn, controls the air gap in a balanced magnetic choke circuit. The measuring base length can be varied between .5 and 5 mm. and the complete instrument only weighs 5.5 gm.

A magnification of the order of 300,000 is easily obtained. The paper gives some examples of the effect of base length on the results.

Impulse Apparatus. (H. Hertwig, E.T.Z., 15/9/38, pp. 981-4. Metropolitan Vickers Techn. News Bulletin, No. 627, 23/9/38, p. 12.) (60/44 Germany.)

The author describes the system of connections, construction and possible applications of an apparatus (developed by the laboratory of the A.E.G. Valve Factory, Berlin) for the production of impulse voltages by means of vapour discharge devices. Variation of the impulse frequency and duration within wide limits is effected by two regulating resistances independent of each other. As an example of the applications of the apparatus, a brief description is given of its use for the speed regulation of a d.c. motor.

Illustrated with seven diagrams and one photograph.

Stroboscopic Measurement of Slip and Speed. (F. Reinhardt, E.T.Z., 8/9/38, pp. 957-60. Metropolitan Vickers Tech. News Bulletin, No. 627, 23/9/38, p. 17.) (60/45 Germany.)

The author describes a stroboscopic method of measuring slip and speed, incorporating a photo-electric cell and relay. The fundamental arrangement, the external construction, precision and ranges of measurement are explained on the basis of practical examples. Illustrated with two photographs, two diagrams and one oscillogram.

Remote Control with Siemen's Equipment Employing the Selector Process. (W. Henning, Siemen's Zeitschrift, August, 1938, pp. 402-6. Metropolitan Tech. News Bulletin, No. 627, 23/9/38, p. 18.) (60/46 Germany.)

The author considers the problem of remote regulation say of transformers, turbines, etc., from the point of view of stepwise regulation, return signalling of the position of the remote-regulated units, the transmission of theoretical values,

stepless regulation and co-operation with automatic control systems. Illustrated with three photographs and two diagrams.

Gyroscopic Instruments for Instrument Flying. (W. G. Brombacher, W. C. Trent, N.A.C.A. Tech. Note No. 662, Sept., 1938.) (60/47 U.S.A.)

The gyroscopic instruments commonly used in instrument flying in the United States are the turn indicator, the directional gyro, the gyromagnetic compass, the gyroscopic horizon, and the automatic pilot. These instruments are described. Performance data and the method of testing in the laboratory are given for the turn indicator, the directional gyro, and the gyroscopic horizon. Apparatus for driving the instruments is discussed.

Dynamic Errors in the Rate of Climb Meter. (C. S. Draper and G. V. Schliestett, J. Aeron. Sci., Vol. 5, No. 11, Sept., 1938, pp. 426-30.) (60/48 U.S.A.)

Rate-of-Climb meters were first described in 1910 by Bestelmeyer,* who recognised the existence of errors due to rapidly changing conditions. However, little quantitative information is available even at the present time on the magnitude of the errors to be expected in particular manœuvres. These " dynamic errors " can be negligible or relatively large depending upon the time required for changes in the actual rate of climb as compared with a period called the " characteristic time " of a particular instrument. If the forcing changes occur in a time much less than the characteristic time, large dynamic errors will appear while slower changes have progressively less effect.

The present paper outlines the general theory of the conventional " capillary leak " rate-of-climb meter and describes a laboratory method for determining the coefficients necessary to predict performance in flight. Theoretical and laboratory results in the form of curves are compared with data taken from flight tests. Special attention is paid to the case of sinusoidal changes, and non-dimensional curves applicable to any frequency are given.

Temperature Measurements of High Speed Gas Currents. (W. Meissner, Forschung, Vol. 9, No. 5, September-October, 1938, pp. 213-218.) (60/49 Germany.)

Experiments were carried out on a whirling arm at top speeds of the order of 125 and 165 m./sec., the thermocouple being either freely exposed or contained inside a short tube facing the air stream. In the latter case measurements were made of the dynamic and static pressure inside the tube.

The reading of the thermocouple is higher than the true gas temperature, but less than the temperature corresponding to the dynamic head (gas reduced to rest adiabatically).

If

dt_1 = measured temperature difference from stationary air.
dt_2 = calculated difference (adiabatic compression).
$(dt_2 - dt_1)/dt_1 = 0.35$ for the particular conditions of these tests.

Some Remarks on the Physical Aspects of the Aircraft Icing Problem. (A. R. Stickley, J. Aeron. Sci., Vol. 5, No. 11, Sept., 1938, pp. 442-6.) (60/50 U.S.A.)

(1) As the size of the water droplets in the air decreases, the amount of aircraft icing becomes vanishingly small since the small suspended drops will fly round the wing and not be deposited. (2) Under certain conditions, it is possible for under-cooled drops to become so large that the excess liquid water

* Bestelmeyer, A., Zur Theorie des Ballonmanometers, Physikalische Zeitscrift, Vol. II, pp. 736-768, 1910.

remaining after their impact will wash away a great part of the ice formed. (3) Assuming that a plane is flying in a cloud in which the usual high humidities prevail, a consideration of certain equations set up by Schumann for the dissipation of the heat of fusion from a hailstone indicates that conduction plays a part considerably more important than that played by evaporation in dissipating the heat of fusion from the ice deposit on the plane. (4) The " icing time " concept of Bleeker offers a possible basis for explaining the peculiarities in shape of the various aircraft ice deposits. (5) No noteworthy reduction of the freezing point of droplets of the sizes which contribute to aircraft icing results from the presence of salt nuclei in them.

The Thermodynamics of Open Systems Applied to the Problem of Rain Production. (G. Van Leberghe and P. Glansdorff, Forschung, Vol. 9, No. 5, Sept.-Oct., 1938, p. 260.) (60/51 Belgium.)

In thermodynamics a closed system is defined as a number of bodies inside a real or imaginary box, the walls of which are transparent to energy but do not allow the transfer of matter.

In the case of an open system, the walls are permeable to both matter and energy.

The authors develop the thermodynamic equations applying to systems of this type, such as a cloud shedding rain or snow.

The Special Duties of a Medical Officer Attached to a Squadron. (H. V. Diringshofen, Luftwehr, Vol. 5, No. 8, August, 1938, pp. 324-326.) (60/52 Germany.)

A considerable proportion of flying accidents is attributed to so-called " errors of judgment." Such errors may be due to a breakdown of the nervous control system of the pilot (brought about by excitement or fear) or they may be definitely psychological (deliberate showing-off to overcome inferiority complex).

In both cases psycho-analytical treatment of the pilot will throw light on his mental worries and thus enable proper rest to be taken before it is too late.

The medical officer, in order to be of help, must be fully conversant with these aspects of medicine and be able to win the confidence of every member of the squadron. It is essential that he should frequently assist at their flights not only with the object of having direct evidence as to the strains involved in their duties, but also to form an opinion of the reaction of the various pilots under difficult circumstances. Modern high speed aircraft is stressing the human element to the limit and accidents can only be avoided if the physiological aspect is properly understood.

In this connection the ordinary routine medical inspection is quite insufficient and must be supplemented as soon as possible by supervision of the mental make-up of the pilot.

New Oxygen Mask Tested by North West Air Lines (U.S.A.). (American Aviation, Vol. 2, No. 6, 15/8/38, p. 15.) (60/53 U.S.A.)

Chief value of the device lies in the fact that it requires much less oxygen, as little as one-tenth as much, it is claimed, as does apparatus now in general use. This cuts down the amount of oxygen that must be carried on planes and thus reduces the weight element.

Another important feature is the design of the mask, which leaves the mouth uncovered, permitting pilots to use standard radio equipment. A new type oxygen tank is used, which is lighter than standard tanks, although retaining the same strength.

The mask is of moulded rubber, consisting of a nosepiece resembling an old-fashioned football noseguard, and a moulded rubber tube that forms a circle from each side of the nosepiece under the mouth. A flexible rubber tube leads down-

ward from this to a valve, which mixes oxygen from the tank with air, and another tube leads from this to the oxygen supply. Below the valve is suspended a small bladder just large enough for a single breath.

A newly-developed reducing valve at the oxygen tank is so designed that it will feed the right amount of oxygen, regardless of the number of masks which it serves. It is claimed that, without affecting the amount of oxygen going to each mask, as many as 30 outlets have been connected to this valve.

Experiments on the Propagation of Ultra Short Wireless Waves. (W. Ochmann and H. Plendl, H.F.T., Vol. 52, No. 2, Aug., 1938, pp. 37-44. In course of translation.) (60/54 Germany.)

The paper deals with field strength measurements carried out with wave length 7.17 and 4.1 m. respectively. The transmitter was placed at some distance, usually of the order of 1,000 m., above normal level, whilst the receiver was placed in an aircraft. The results can be explained (at any rate qualitatively) by refraction of the rays in the lower layers of the atmosphere (reduction in dielectric constant with height). As a result of refraction, rays may enter the shadow region and be subsequently reflected upwards. This would produce the pronounced maxima and minima observed in the field strength diagrams. Variation in the refractive index with time and season would also account for the changes in this phenomenon as well as for vagaries in the possible range.

How Ultra Short Waves Overcome the Curvature of the Earth by Refraction. (G. Eckart and H. Plendl, H.F.T., Vol. 52, No. 2, Aug., 1938, pp. 44-58. In course of translation.) (60/55 Germany.)

Expressions are obtained for the variation with height of the dielectric constant of the atmosphere and with the help of these data the path of a ray originating at some point above the surface of the earth is calculated. Applying next the laws of reflection, the field strength can be calculated as a function of height and distance. The results are in satisfactory agreement with experiment and it can be considered as definitely established that range in excess of 100 km. with wave length λ of the order of 10 m. $> \lambda >$ 10 cm. are entirely due to refraction in the atmosphere.

It follows from this that the maximum possible range (*i.e.*, position of lowest minimum on vertical field diagram) is fixed by atmospheric conditions and independent of power output.

A Unique Method of Modulation for High Fidelity Television Transmitters. (W. N. Parker, Proc. Inst Rad. Eng., Vol. 26, No. 8, August, 1938, pp. 946-62.) (60/56 U.S.A.)

Present-day high fidelity 441-line television demands modulation frequencies as high as 4 megacycles. Tube capacitance and the flywheel effect of resonant circuits make such modulation difficult and inefficient when conventional methods are used.

The author describes a system called " transmission line modulation " in which modulation is effected between the radio frequency generator and the antenna by means of a variable impedance, connected across the radio-frequency transmission line. This impedance, consisting of a quarter-wave line terminating in the modulator tubes, is controlled by the voltage applied to the grids of these tubes.

At high video frequencies the plate efficiency and degree of modulation compare favourably with the conventional systems employed in sound broadcasting.

A one kilowatt experimental television transmitter employing this system, which may be modulated 80 per cent. at frequencies up to 5 megacycles, is described. For demonstration purposes a 200-megacycle oscillator, modulated at frequencies up to 20 megacycles, is shown.

Electrical Interference with Radio Reception. (A. J. Gill and S. Whitehead, J. Inst. Elec. Eng., Vol. 83, No. 501, Sept., 1938, pp. 345-94.) (60/57 Great Britain.)

The paper describes the method of assessment of the interference to radio reception from electrical equipment, and determines the level to which such interference must be reduced to permit satisfactory service.

The methods of achieving this result are described for the various classes of interfering equipment. Although mainly directed towards the protection of broadcast reception, the principles described apply equally to other radio communication services.

The Theory of Diffraction Applied to the Propagation of Ultra Short Wireless Waves. (G. Eckart, H.F.T., Vol. 52, No. 2, Aug., 1938, pp. 58-62. In course of translation.) (60/58 Germany.)

In its broad aspect the theory of diffraction deals with the propagation of wireless waves in the presence of conductors. In our case, the only conductor of importance is the earth itself and the author shows that in the case of ultra short waves (5-10 m.) the surface wave is damped out within a very short distance (few km.) of the transmitter. To obtain measurable diffraction effects at the practical ranges would imply an enormous power output of the transmitter. Refraction alone can thus account for the observed results and similar conclusions are reached by Pol-Bremmer, whose work is briefly reviewed by the author.

Twenty-five references.

Electrical Installations on Board Aircraft. (H. Vickmann, E.T.Z., Vol. 59, No. 14, 7/4/38, pp. 361-6. Available as Translation No. 725.) (60/59 Germany.)

The requirements imposed on electrical apparatus installed in aircraft are briefly enumerated and the special design feature of generators and electric circuits are described.

Considerable space is devoted to the design of automatic switches, cut-outs and navigation lights.

Ignition systems and radio shielding are briefly described, but no reference is made to radio equipment, which forms the subject of a separate report (R. Bruger, Radio Equipment on Board Commercial Aeroplanes, E.T.Z., Vol. 58, 1937, p. 915).

Measurement of Transparency of Electric Insulators to Thermal Radiations. (E. Eckert, Forschung, Vol. 9, No. 5, Sept.-Oct., 1938, pp. 251.) (60/60 Germany.)

The measurements were carried out electrically by comparing the amount of radiation received by a thermopyle when various types of insulators were placed in front of a black body radiator. The substances tested included glass, mica, paper and rocksalt. A layer 1 mm. thick of the first three materials absorbed the thermal radiations completely, whilst the rock salt, although being opaque to radiations greater that 16 μ was transparent to radiations of lower wave lengths.

According to the electro-magnetic theory of light, electric insulators should be transparent to thermal radiations. The fact that in many cases such transparency is not found in practice is now known to be due to resonance phenomena in the atomic lattice. Since this effect depends on the frequency of the radiation, transparency to light rays gives no clue as to the absorption of the longer heat waves.

LIST OF SELECTED TRANSLATIONS.

NOTE.—Applications for the supply of copies of translations mentioned below should be addressed to the Under-Secretary of State, Air Ministry (R.T.P.), Kingsway, W.C.2, and will be supplied free of charge as far as availability of stocks permit.

Suggestions concerning new translations will be considered in relation to general interest and facilities available.

AIRCRAFT (PERFORMANCE AND DESIGN).

TRANSLATION NO. AND AUTHOR.		TITLE AND JOURNAL.
709	Bock, G. ... ... Nikodemus, R. ...	*Propeller Efficiencies at High Flying Speeds.* (L.F.F., Vol. 15, No. 7, 6/7/38, pp. 334-339.)
710	Lorenzelli, E. ...	*Graphical Investigations of the Coefficients of Resistance and of Hydrodynamic Moment of a Hydroplane and the Determination of the Best Wing Setting.* (L'Aerotecnica, Vol. 18, No. 1, January, 1938, pp. 64-77.)
721	Kohler, M.	*Wind Tunnel Experiments on Strut Joints.* (L.F.F., Vol. 15, No. 4, 6/4/38, pp. 143-52.)

AERODYNAMICS AND HYDRODYNAMICS.

602	Ruden, P.	*Investigations on Single-Stage Axial Blowers.* (Luftfahrtforschung, Vol. 14, No. 7, 20/7/37, pp. 325-46, and No. 9, 20/9/37, pp. 458-73.)
697	Bühne, W.	*Heat Transfer in Viscous Liquids During Turbulent Flow.* (Jahrbuch der Deutschen Luftfahrtforschung, 1937, Vol. 2, pp. 57-66.)
712	Frank, A. ... ... Weinig, F.	*Aerofoil and Propeller Slipstream.* (L.F.F., Vol. 15, No. 6, 6/6/38, pp. 303-14.)
726	Schmidt, H.	*Introductory Remarks on a Series of Papers Dealing with the Results of Prandtl's Aerofoil Theory.* (L.F.F., Vol. 15, No. 5, 6/5/38, pp. 219-22.)

ENGINES AND ACCESSORIES.

715	Vogt, R.	*Lines of Development in Engine Mountings.* (Luftwissen, Vol. 5, No. 5, May, 1938, pp. 164-6.)
727	Schmidt, F. A. F. ...	*Theoretical and Experimental Investigation of the Combustion Process of Spark-Ignition and Compression-Ignition Engines.* (L.F.F., Vol. 14, No. 12, 20/12/37, pp. 640-6.)

MATERIALS AND ELASTICITY.

713	Nikiforov, N. G. ...	*Calculation of the Strength of a Family of Airscrews.* (Aeron. Eng., U.S.S.R., Vol. 8, No. 1, January, 1934, pp. 5-51.)
735	Thum, A.	*Ordinary Fracture, Limited-Time Fracture, and Fatigue Fracture—Appearance of the Fracture Under Tension, Bending and Torsion.* (Forschung, Vol. 9, No. 2, March-April, 1938, pp. 57-67.)

INSTRUMENTS.

TRANSLATION NO. AND AUTHOR.	TITLE AND JOURNAL.
718 Masini, C.	*Installation for Testing Electrical Aircraft Accessories Under High Altitude Conditions.* (Rivista Aeronautica, Vol. 15, No. 2, Feb., 1937, pp. 245-55.)
725 Viehmann, H. ...	*Electrical Installations on Board Aircraft.* (E.T.Z., Vol. 59, No. 14, 7/4/38, pp. 361-6.)

WIRELESS.

714 Allerding, A. ... Dallenbach, W. ... Kleinstauber, W. ...	*The Resotank Generator for Micro Waves.* (H.F. Technik, Vol. 51, No. 3, March, 1938, pp. 96-9.)
705 Niessen, K. F. ...	*The Field Around a Vertical Half-Wave Antenna at any Height Above Flat Ground having Dielectric and Conductivity Constants of any Value.* (Annalen der Physik, Vol. 31, No. 6, March, 1938, pp. 523-30.)

PHYSIOLOGY.

728 Clamann, H. G. ... Hartmann, H. ...	*Cooling of the Blood in the Aorta when Breathing Cold Air and the Effect on its Ability to Combine with Oxygen.* (Jahrbuch der Deutschen Luftfahrtforschung, Vol. 3, 1937, pp. 118-22.)
729 Hartmann, H. ...	*The Effect of Altitude Adjustment on the Behaviour of the Pulse and on Muscular Force Under Conditions of Oxygen Deficiency.* (Jahrbuch der Deutschen Luftfahrtforschung, 1937, Vol. 3, pp. 111-7.)
730 Diringshofen, H. V...	*To What Extent Can Humans Stand Centrifugal Forces in Aircraft and What is the Effect of Change in Position of the Body.* (Jahrbuch der Deutschen Luftfahrtforschung, 1937, Vol. 3, pp. 128-30.)
731 Ruff, S.	*Fibula Fractures Occurring During Flight: a Typical Injury Caused by Centrifugal Forces.* (Jahrbuch der Deutschen Luftfahrtforschung, 1937, Vol. 3, pp. 131-2.)
732 Ruff, S.	*Contamination of Breathing Air in Aircraft by Exhaust Gases and its Significance with Respect to the Efficiency of the Crew.* (Jahrbuch der Deutschen Luftfahrtforschung, 1937, Vol. 3, pp. 133-9.)
733 Ruff, S.	*Head Injuries in Flying Accidents. Their Cause and Methods for Reducing Them.* (Jahrbuch der Deutschen Luftfahrtforschung, 1937, Vol. 3, pp. 140-3.)
734 Ranke, O. F. ...	*Effect of Acceleration on the Human Circulation. Experiments on the Effect of Acceleration in a Centrifuge on Men and Animals.* (Jahrbuch der Deutschen Luftfahrtforschung, 1937, Vol. 3, pp. 123-7.)

REVIEWS.

W. Zuerl: "Fortschritte in Luftfahrt und Flugtechnik" (Progress in Aeronautics and in Aviation). Muenchen, 1938. Publ. by Curt Pechstein Verlag. 536 pp. with num. tabl., phot., and fig. Price RM. 8.—.

Some years ago and before the Great War a valuable technical yearbook used to be published regularly in Germany bearing the above title; it was edited by Ansbert Vorreiter (pre-war volumes) and afterwards by Dr. v. Langsdorff. The reader might assume the present volume to be a worthy continuation of these progress yearbooks published up to 1932 but, unfortunately, it is not. In comparison with the former "Fortschritte der Luftfahrt" context and pictures are definitely not up to the standard of the previous volumes. The photographic reproductions are of a poor quality, the paper seems to be "Ersatz," the lists of aircraft and engines are neither complete nor reliable, and the text is mostly composed of excerpts collected from technical papers and not very well done. For an average German book, even the style is bad. Incidentally, the greater number of the constructional detail sketches is taken from English periodicals.

A few characteristic technical curiosities extracted from this book may be worth while mentioning as illustrations. The reader is informed that "Alclad" composite aluminium alloys are formed by "welding" a layer of "pure or copper-free" aluminium to the alloy material core; that compressed "improved" wood is "lighter" than plywood; that certain well-known fin and tailplane arrangements "prevent" spinning; that the wings of Douglas DC. 3 monoplanes are built "without spars"; that radial engines suffer "from unequal heat distribution"; that single-cylinder test devices for full-scale research are a recent American innovation (poor Mr. Ricardo); that sleeve valve control has to be considered in connection with swash plate drive; that this country has never built any serviceable compression ignition engine, etc., etc.

H. Schneider: "Flugzeug-Typenbuch. Handbuch der Deutschen Luftfahrt-Industrie" (Aeroplane Type Book. Handbook of the German Aircraft Industry). 2nd edition. Leipzig, 1937-38. With a complementary addition (referring to 24 new aeroplane types). Publ. by Herm. Beyer Verlag. 584-24 pp. with num. fig. and photographs.

This handbook contains tables of German aeroplane types, of sailplanes, parts, engines, airscrews, instruments, etc., of German manufacture in a neatly arranged form on separate pages complete with photographs, outline drawings, description and data. Tools, machine tools, tests plants of every kind, demonstration and scientific devices, sheds, searchlights and other aerodrome equipment are also included. Attached is a—not too complete—list of German firms connected with aeronautical matters.

Unfortunately, the data given are solely those released by the publication departments of the firms concerned and, therefore, the performance data given tor aeroplanes and engines seem neither reliable nor exact enough for any comparisons or for statistical purposes. With aeroplane types, certain of the ultimate load factors stated for case "A" appear to be rather on the low side (3.75 for flying boat types of medium size, 5.2 for private owner two-seater land planes, for instance).

Otherwise, this handbook should certainly have a good propaganda value, and the aeronautical industry of this country might do well to publish something like this of its own.

CL. BOEHNE: "FLUGZEUGWARTUNG I, DIE WARTUNG DES TRIEBWERKS" (Aeroplane Maintenance I, the Maintenance of Power Groups). Berlin, 1938. Publ. by C. J. E. Volckmann Nachf. E. Wette, Berlin-Charlottenburg. 134 pp. with 106 fig. Price RM. 3.—.

This book is intended for the instruction of ground engineers, and as the author is serving as an instructor with a technical school of the German Air Force, his book gives a first-class survey of the duties and knowledge expected from a German air mechanic. Fortunately, it is by no means compiled from extracts copied from engine manuals and pamphlets of manufacturers as most instruction books of this kind are, but it covers everything necessary in a thoroughly practical and systematic manner:—Fuels (including the handling of leaded petrol), fuel systems, cooling, airscrew handling, engine treatment (starting, testing, trouble chasing), general maintenance of power groups, inspection and overhaul, hints for repair work and remarks concerning the servicing of Junkers compression ignition engines, which apparently require special attention. A good point is that the author does not refrain from giving explanations for physical and mechanical phenomena which the mechanic will encounter in his task, and that he likes to illustrate as often as possible the sad result of forgetfulness or foolishness on the part of the mechanic, by means of good photographs. Even the designing engineer might discover some useful practical hints in this book.

DR.-ING. ARVO YLINEN: "DIE KNICKFESTIGKEIT EINES ZENTRISCH GEDRUECKTEN, GERADEN STABES IM ELASTISCHEN UND UNELASTISCHEN BEREICH" (The crippling strength of a centrally compressed straight beam in the elastic and inelastic range). Helsinki (Finland), 1938. Sold by Akateeminen Kirjakauppa, Helsinki. 131 pp. with 53 diagrams and 19 tables. Price, Finnish Marks 70.—.

The author, a technical director of the Finnish Government Aircraft Factory, had the facilities to undertake an extensive research into important problems of crippling strength. In this paper (written as a thesis for a Doctor of Engineering) he develops a new, general valid law for the deformation of materials which is adapted to steel, electron, pine wood, etc., under crippling loads. From this law a function for a generalised Young's modulus is deduced which is dependant on the stress-strain properties of materials outside the elastic range, and which incorporates test figures gained with compression tests beyond the proportionality limit. The introduction of this functional Young's modulus into the classic crippling formula of Euler (generalised by Engesser) results in a new and useful relation for the crippling strength. This new formula is considered valid up to the yield point. Experimental values are given for the influence of lasting deformations due to crippling loads for materials commonly used in aeronautics. The author further proves theoretically that the minimum crippling stress of all beam cross sections concerned is obtained with a T-section. Useful nomograms are given for the calculation of cross sectional areas for beams under a given crippling load, and comparisons with crippling tests indicate that the author's formula is in good agreement with the results.

The paper is a valuable and instructively written contribution to practical problems of crippling strength in aeronautics.